2017年3月2日-3日
於・国立極地研究所

NiPR
National Institute of Polar Research

サブミリ波・テラヘルツ帯での広域銀河探査

Wide-area galaxy surveys at submm – terahertz wavelengths

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Contents

- Roles of multi-color photometric surveys at submm to terahertz wavelengths
  - We observe thermal emission from dust in galaxies
  - Why dusty objects?
  - Why submm/THz?
- Proposed possible survey strategy using Antarctic THz 10m/30m telescopes
  - Lessons from Herschel Astrophysical Terahertz Large Area Survey (H-ATLAS) etc.
  - Synergy with The South Pole Telescope 2500 deg^2 survey

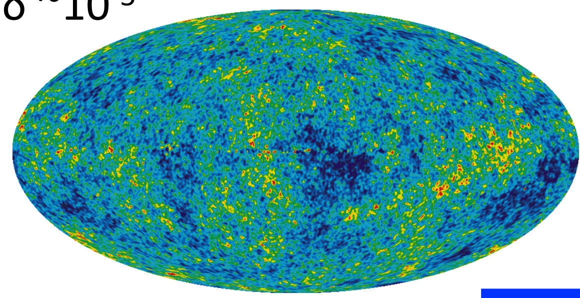
Our current understanding of galaxy formation and evolution

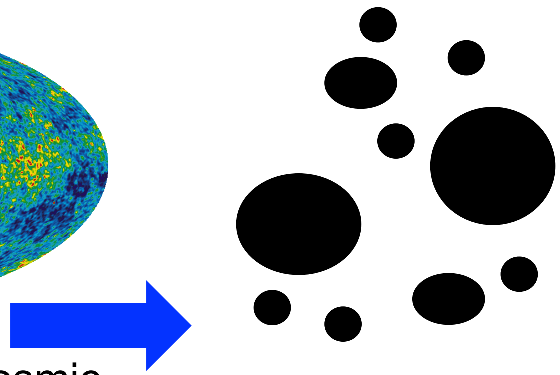
Inflation ➔ Tiny density fluctuation

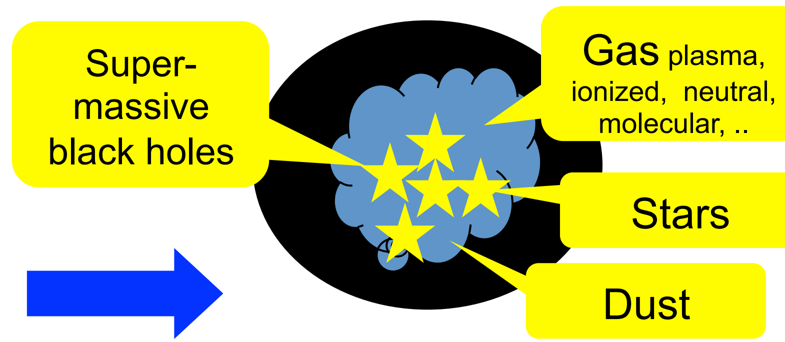
Growth of dark matter halos

Infall of baryons into dark matter halos ➔ formation & growth of galaxies

δ ~10^{-5}



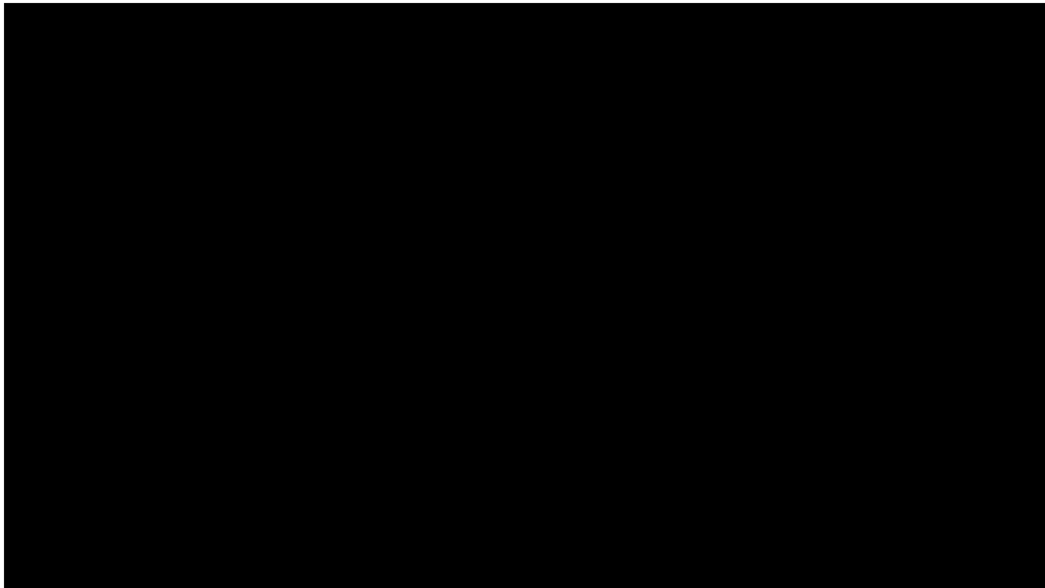




A temperature map of cosmic microwave background (CMB) imaged by WMAP

redshift ~1100 (13.7 Gyr ago)

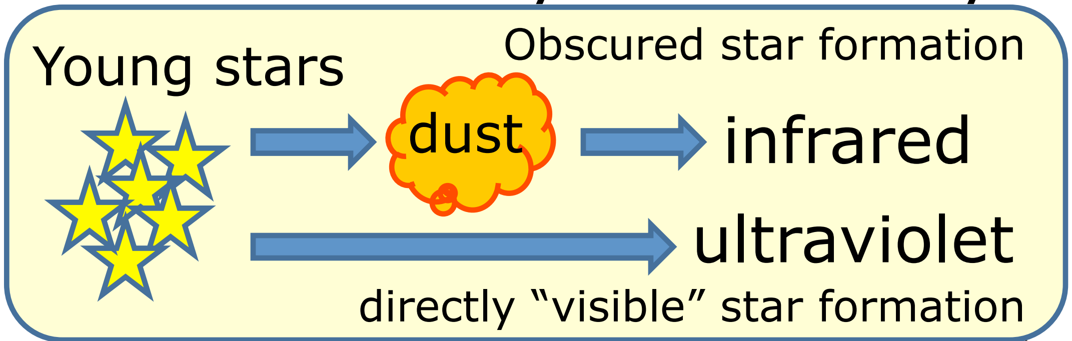
- most distant galaxy known: z ~ 11.09 (13.3 Gyr ago)
- re-ionization: z ~ 6-20 ? (12.8 – 13.5 Gyr ago ?)
- first stars: z ~ 30 ?? (13.6 Gyr ago ??)
- recombination, "transparent to radiation": z ~ 1100

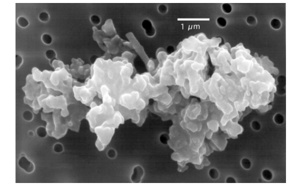


Simulation of dark matter & gas temperature distribution with ΛCDM

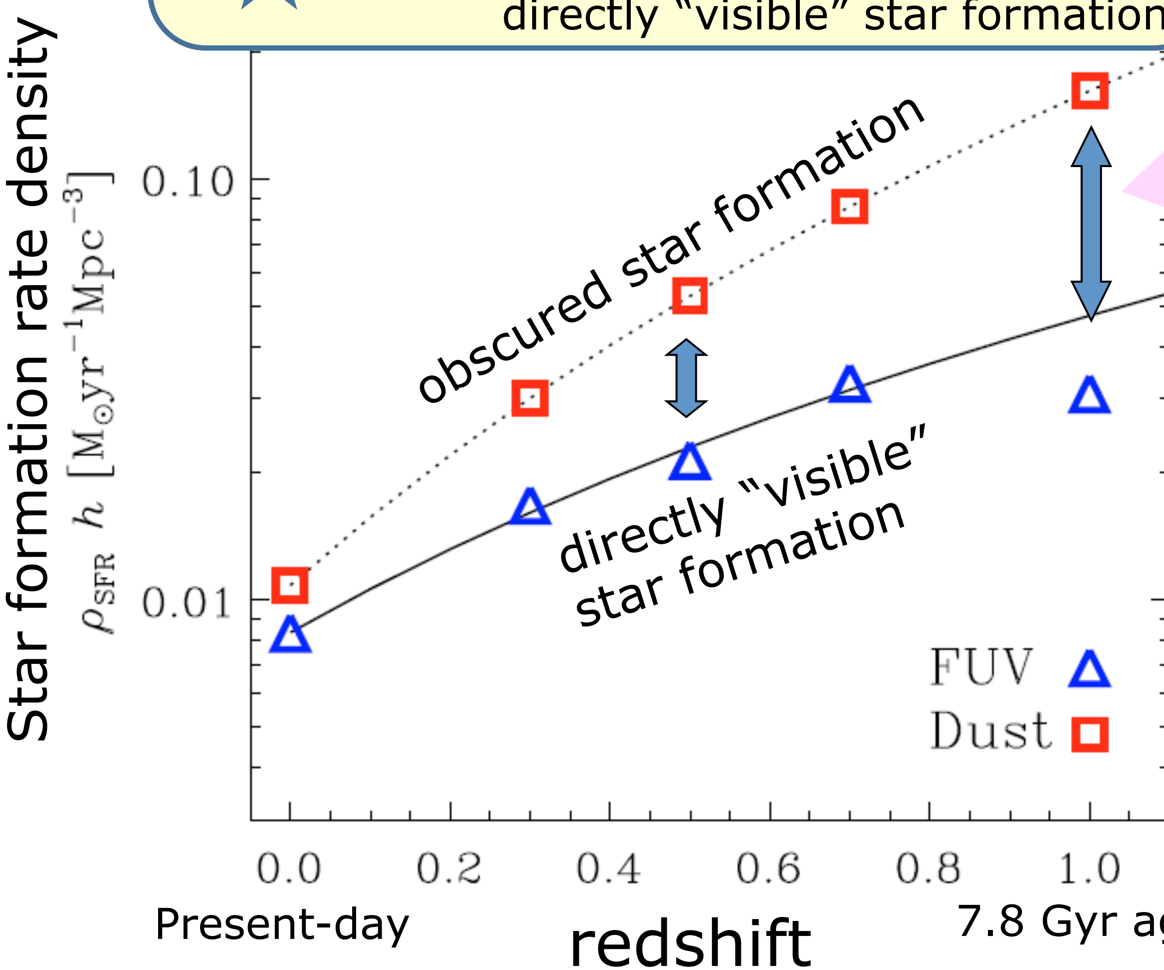
http://www.illustris-project.org/media/

Galaxies in their forming & evolving phases are often heavily obscured by cosmic dust





minerals,
up to ~1 μm
in size



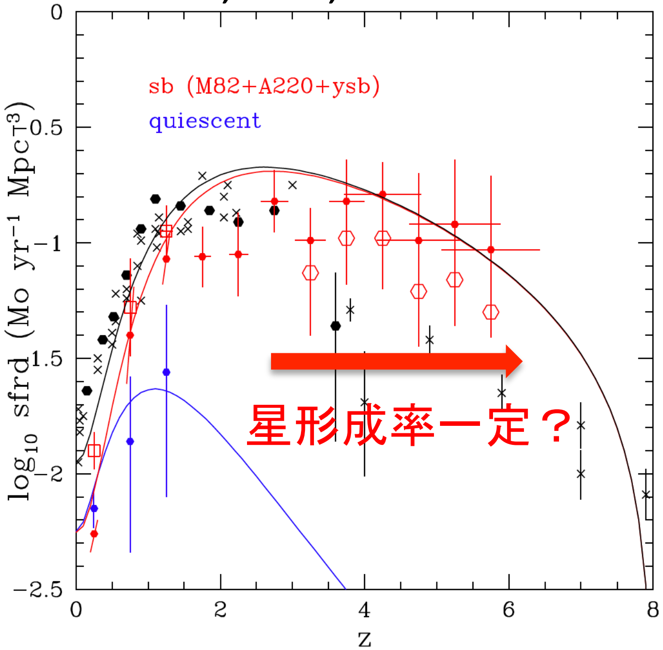
More obscured star forming activities in earlier epoch of the universe

>70% is obscured
@7.8 billion yrs ago

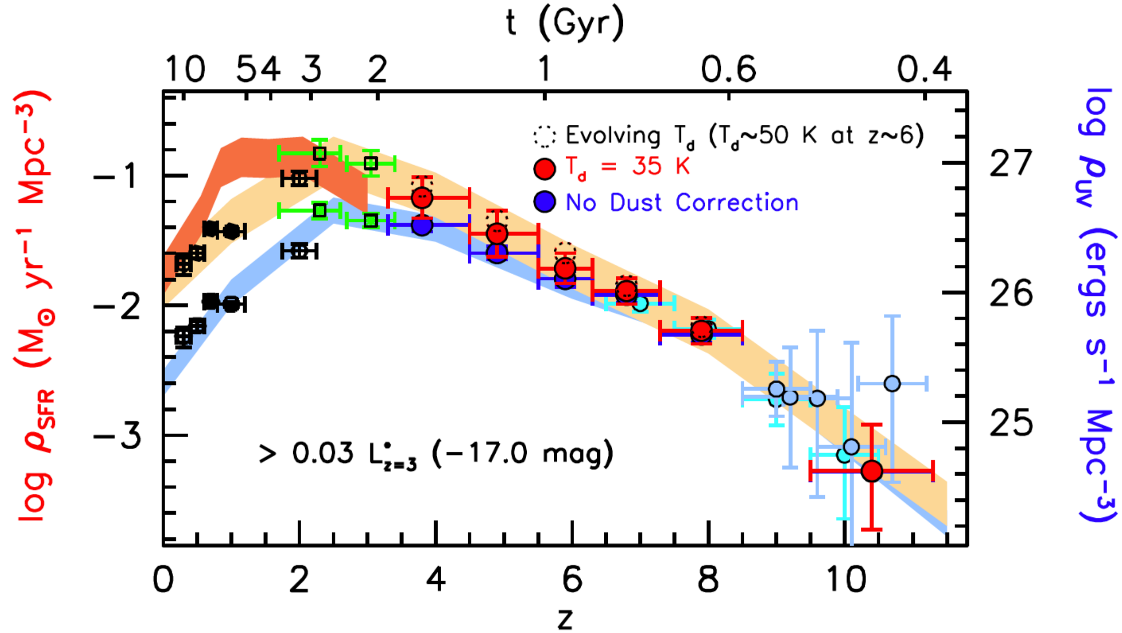
Takeuchi et al. 2005, A&A, 440, L17

What is the cosmological role of dusty star-formation?

Rowan-Robinson et al. 2016, MNRAS, 461, 1100

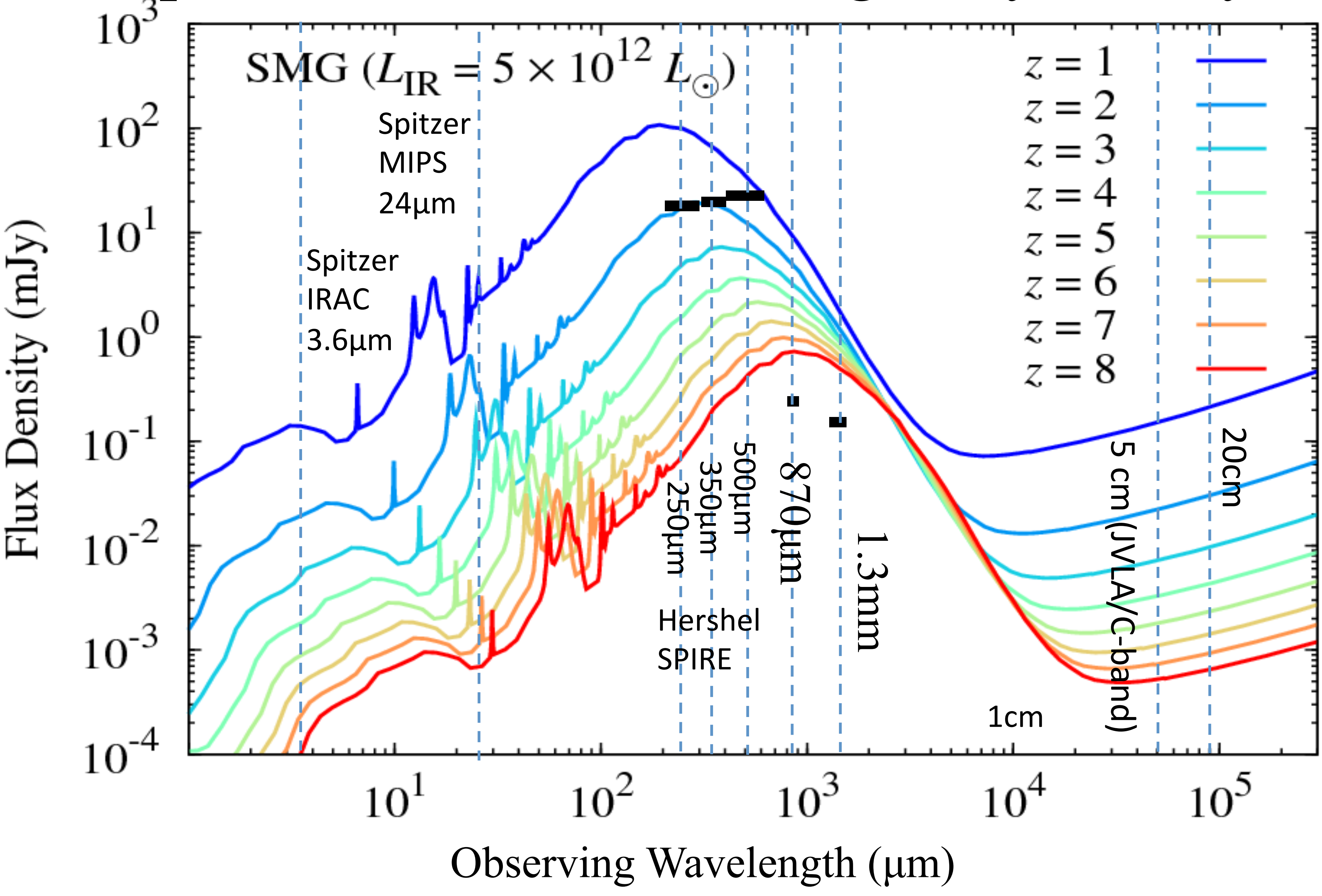


Bouwens et al. 2016, ApJ, 833, 72



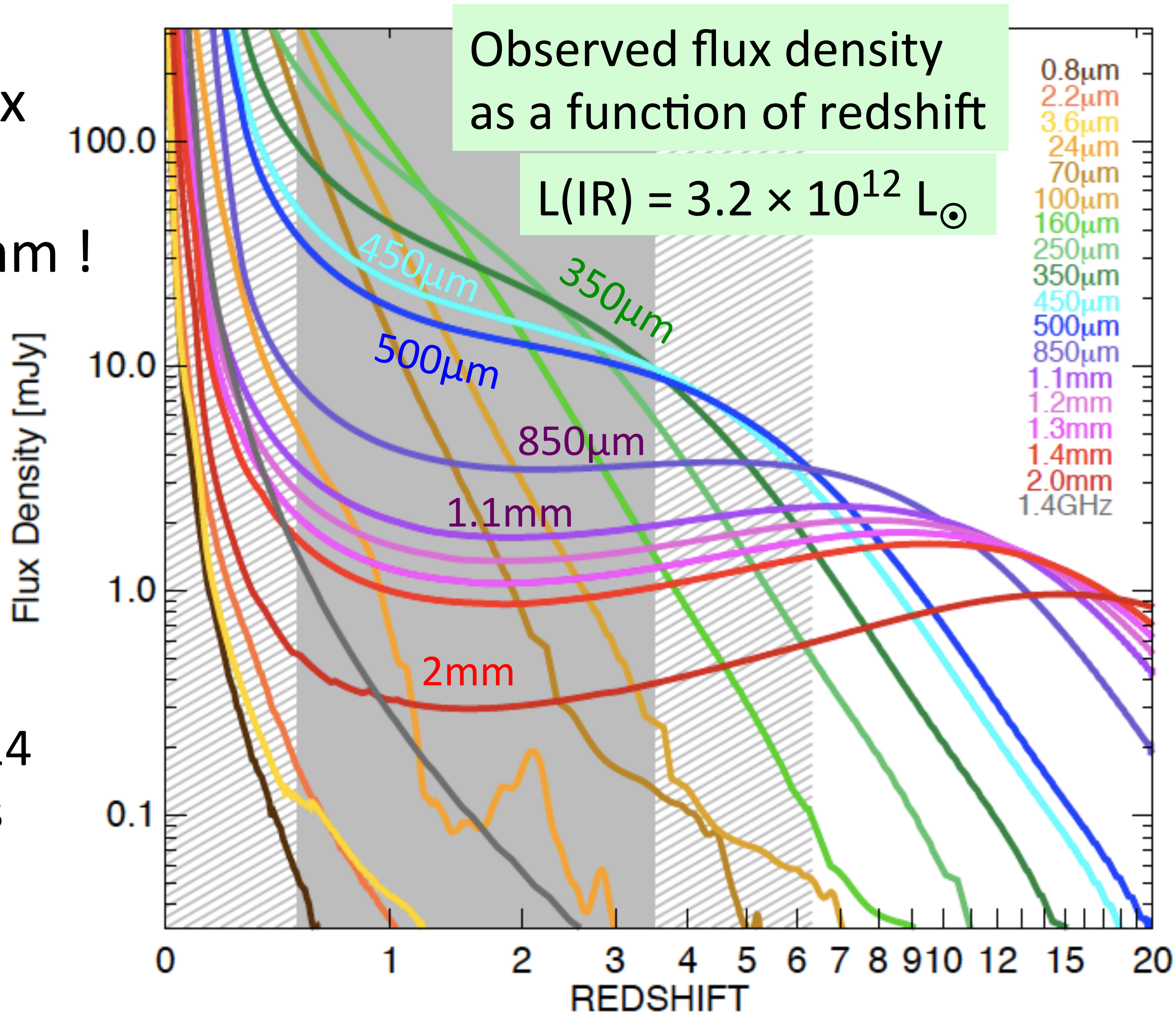
- is dusty star-formation significantly contributing to star formation rate density at z > 4?
  - Lyman break galaxies (LBGs) at ALMA deep survey@HUDF ➔ dusty star formation is rather minor role (Bouwens et al.)
    - Importance of shorter submm bands is emphasized
  - Herschel-selected red sources ➔ almost constant SFRD at least up to z~6 !?

Uniqueness of mm/submm galaxy surveys



Strong negative K-correction @mm/submm gives a uniform selection function for high-z dusty galaxies

Almost flat flux for 1 < z < 10 around λ ~ 1mm !

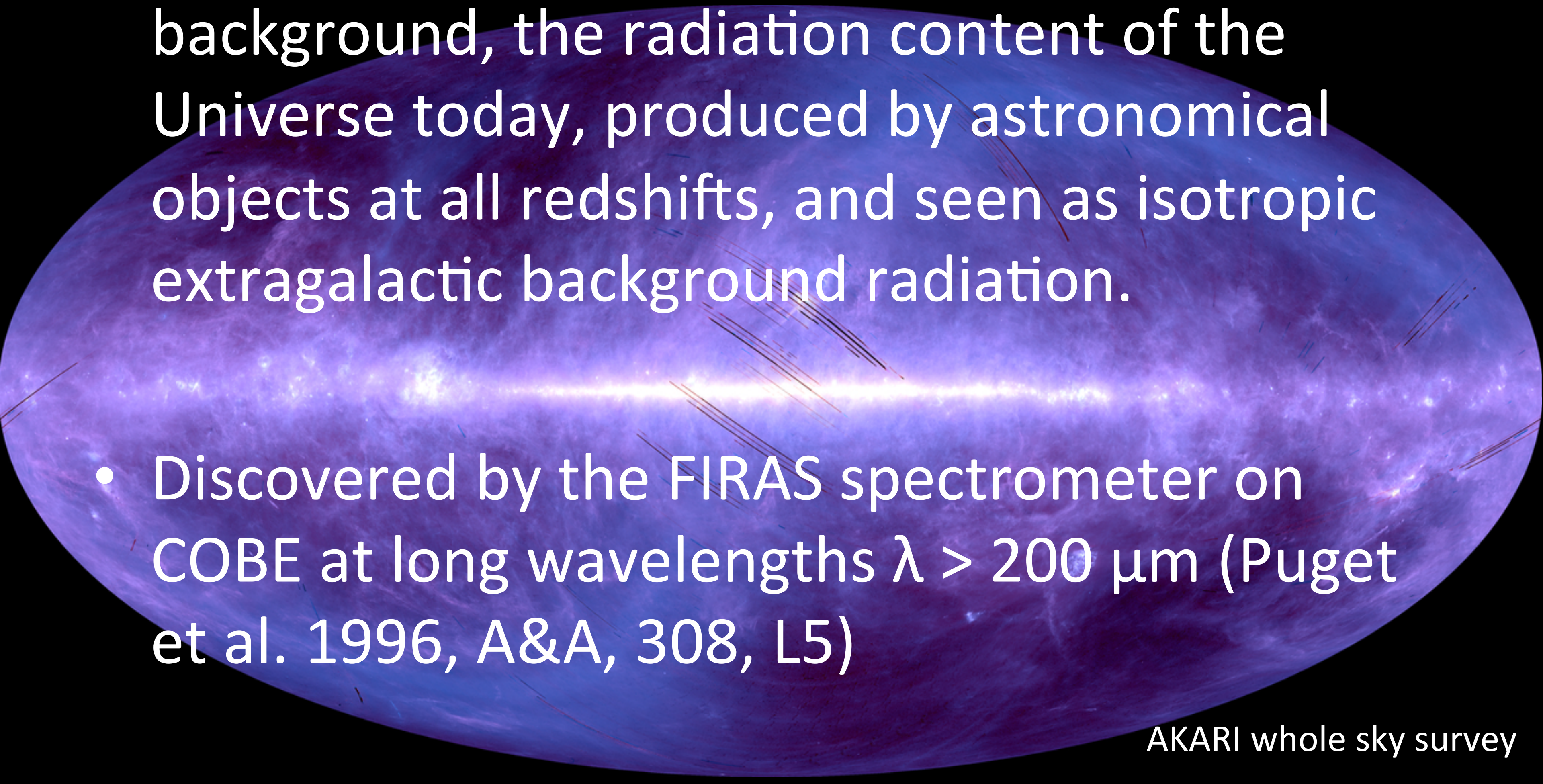


Casey et al. 2014 Physics Reports 541, 45

The cosmic infrared background (CIB)

- The infrared part of the extragalactic background, the radiation content of the Universe today, produced by astronomical objects at all redshifts, and seen as isotropic extragalactic background radiation.

- Discovered by the FIRAS spectrometer on COBE at long wavelengths $\lambda > 200$ µm (Puget et al. 1996, A&A, 308, L5)



AKARI whole sky survey

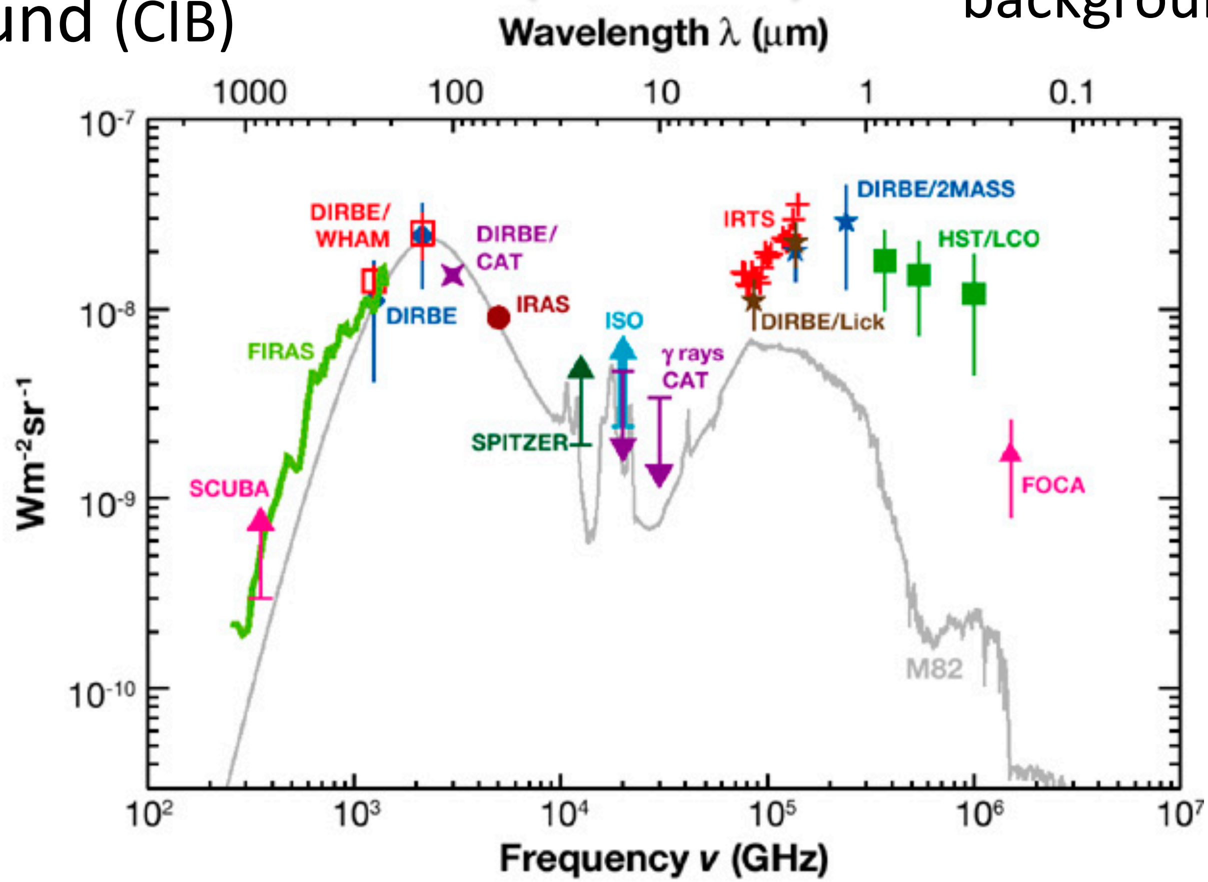
CIB: what is the origin?

In contrast, the infrared output of galaxies at z=0 is only 1/3 of the optical output.
➔ infrared galaxies grow more luminous with increasing z faster than optical galaxies

The cosmic infrared background (CIB)

Comparable !!!

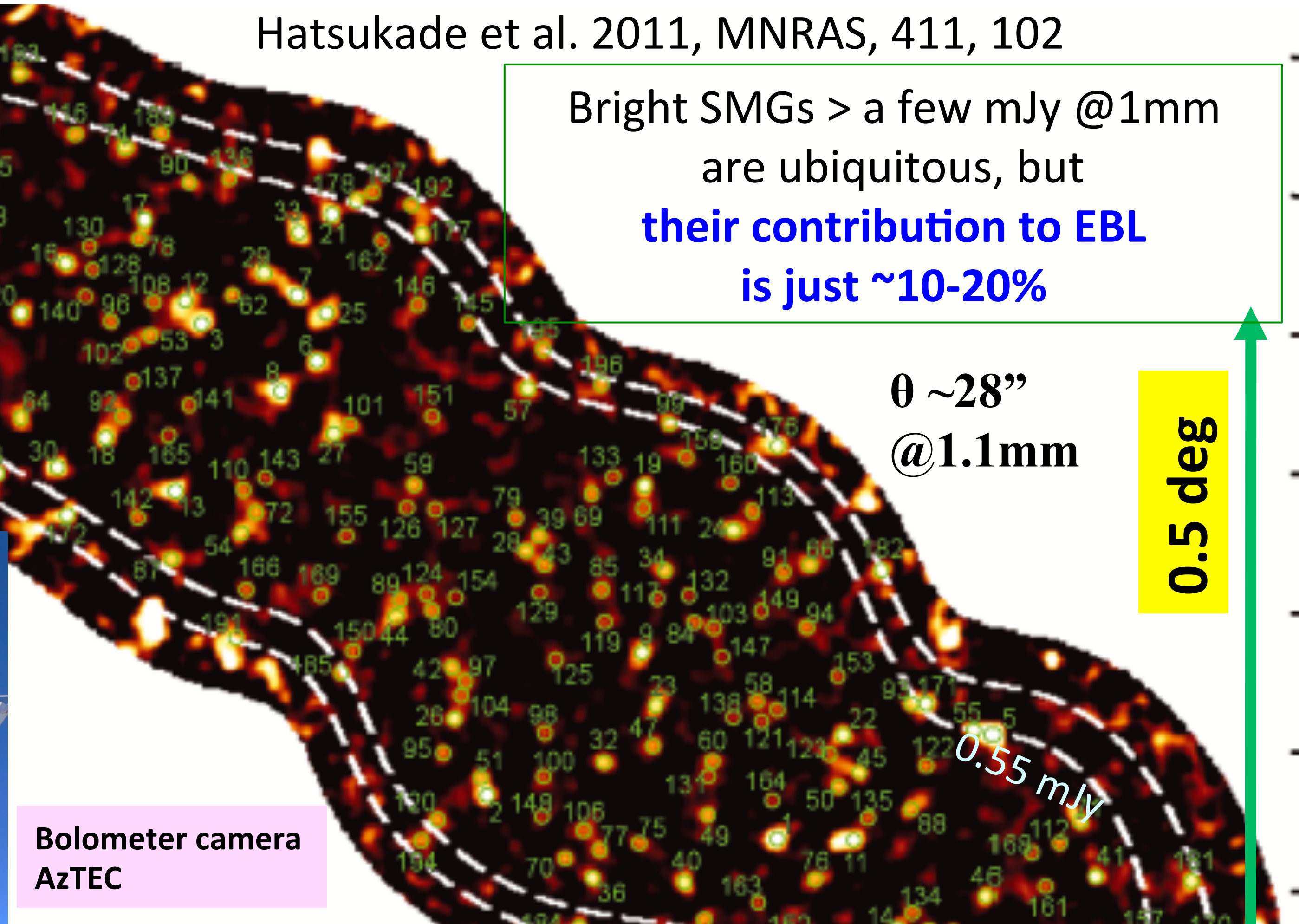
The cosmic optical background (COB)



http://ned.ipac.caltech.edu/level5/March05/Lagache/Lagache3.html

“Submm galaxies” are bright, but..

Hatsukade et al. 2011, MNRAS, 411, 102



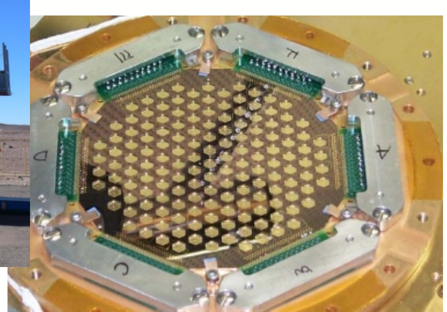
Bright SMGs > a few mJy @1mm
are ubiquitous, but
their contribution to EBL
is just ~10-20%

θ ~28”
@1.1mm

0.5 deg

ASTE
10m

Bolometer camera
AzTEC



233 sources
0.4 - 0.8 mJy (1σ)
area ~0.25 deg^2

Deep photometric survey strategy

- Which is the most unique band in Antarctic 30-m telescope?
- Do we really need blind surveys at short-submm bands?
- How many bands (colors) do we need?
- Where is the right place for Antarctic 30-m telescope deep survey?

confusion limits (5σ) of mm/submm telescopes

Unit: mJy

	LMT, LST	NRO	IRAM, SST, 南極	CCAT	JCMT	APEX	CSO, ASTE, GLT, Tsukuba	SPT 1.2'@2mm, 1.0'@1.4mm	Herschel
Dish D	50m	45m	30m	25m	15m	12m	10m	10m※	3.5m
3.3mm	0.052		0.084	0.098	0.15	0.17	0.20		0.40
2.0mm	0.13		0.23	0.28	0.44	0.53	0.61	1.4?	1.22
1.3mm	0.29		0.58	0.72	1.2	1.5	1.7	2 – 4?	3.50
1.1mm	0.36		0.78	0.97	1.7	2.0	**2.0,** 2.4		4.94
860μm	0.42		1.02	1.3	2.3	2.9	3.4		7.36
750μm	0.53		1.37	1.8	3.2	4.0	4.8		10.28
500μm									**30.5**#
450μm	0.26		1.5	2.2	4.8	6.3	7.6		18.0
350μm	0.058		1.0	1.8	4.7	6.4	8.0		**27.5**# , 20.7
200μm	0.0008		0.04	0.17	1.7	2.9	4.2		17

Bold font: based on the measured number counts

#: Oliver et al. 2012, MNRAS, 424, 1614

Adopted number counts: Bethermin et al. (2012); definition of confusion: 30 beams per source

confusion limits (5σ) ➔ fraction of CIB resolved

Unit: mJy

	LMT, LST	NRO	IRAM, SST, 南極	CCAT	JCMT	APEX	CSO, ASTE, GLT, Tsukuba	SPT 1.2'@2mm, 1.0'@1.4mm	Herschel
Dish D	50m	45m	30m	25m	15m	12m	10m	10m※	3.5m
3.3mm	19.3%		10.5%	8.4%	4.4%	3.3%	2.6%		0.7%
2.0mm	34.3%		19.6%	15.8%	8.4%	6.3%	4.9%	1.4?	1.2%
1.3mm	51.1%		30.7%	[illegible]	[illegible]	[illegible]	[illegible]	2 – 4?	2.0%
1.1mm	58.3%		36.0%	[illegible]	[illegible]	[illegible]	[illegible]		2.4%
860µm	70.2%		45.3%	[illegible]	[illegible]	[illegible]	[illegible]		3.2%
750µm	75.5%		49.7%	[illegible]	[illegible]	17.9%	14.3%		3.5%
500µm									
450µm	95.4%		73.8%	64.1%	39.2%	30.6%	24.7%		6.4%
350µm	99.2%		86.3%	77.6%	50.9%	40.6%	33.3%		9.3%
200µm	99.9%		99.6%	98.2%	83.0%	72.6%	63.6%		24.1%

350 µm band: dramatic improvement by Antarctic 30-m telescope!

Bold font: based on the measured number counts

#: Oliver et al. 2012, MNRAS, 424, 1614

Adopted number counts: Bethermin et al. (2012); definition of confusion: 30 beams per source

confusion limits (5σ) ➔ fraction of CIB resolved

Unit: mJy

	LMT, LST	NRO	IRAM, SST, 南極	CCAT	JCMT	APEX	CSO, ASTE, GLT, Tsukuba	SPT 1.2'@2mm, 1.0'@1.4mm	Herschel
Dish D	50m	45m	30m	25m	15m	12m	10m	10m※	3.5m
3.3mm	19.3%		10.5%	8.4%	4.4%	3.3%	2.6%		0.7%
2.0mm	34.3%		19.6%	15.8%	8.4%	6.3%	4.9%	1.4?	1.2%
1.3mm	51.1%		30.7%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible] – 4?	2.0%
1.1mm	58.3%		36.0%	[illegible]	[illegible]	[illegible]	[illegible]		2.4%
860µm	70.2%		45.3%	[illegible]	[illegible]	[illegible]	[illegible]		3.2%
750µm	75.5%		49.7%	41.5%	23.5%	17.9%	[illegible]		3.5%
500µm									
450µm	95.4%		73.8%	64.1%	39.2%	30.6%	2[illegible]%		6.4%
350µm	99.2%		86.3%	77.6%	50.9%	40.6%	33[illegible]%		9.3%
200µm	99.9%		99.6%	98.2%	83.0%	72.6%	63.6%		24.1%

200 µm band: even in 10-m dish, majority of the CIB contributors can be captured

Bold font: based on the measured number counts

#: Oliver et al. 2012, MNRAS, 424, 1614

Adopted number counts: Bethermin et al. (2012); definition of confusion: 30 beams per source

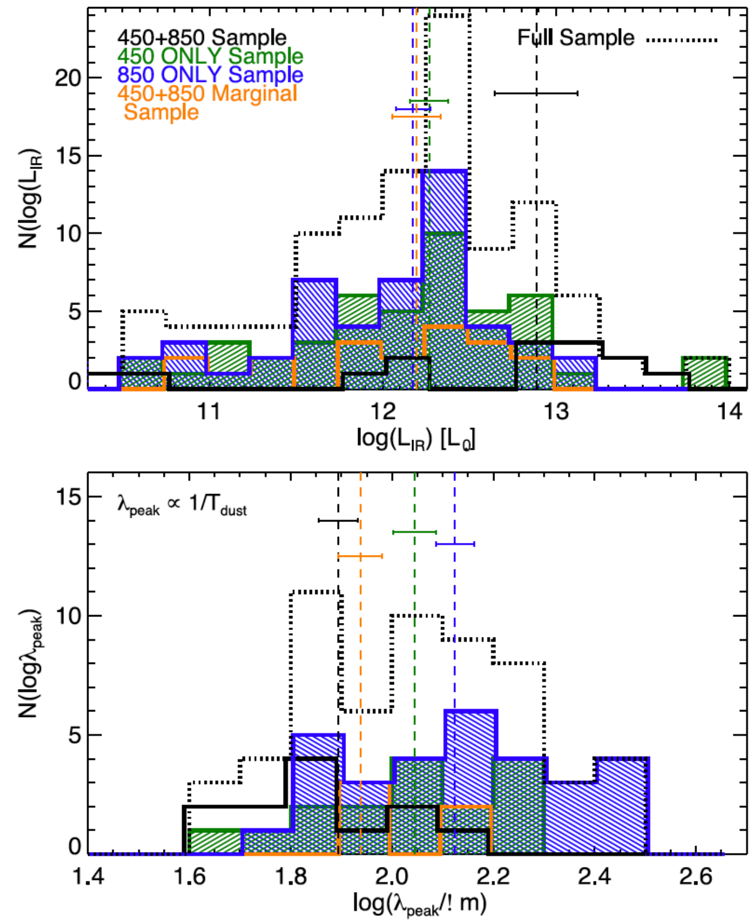
From Herschel to Antarctic 10m → 30m terahertz telescope

- Herschel SPIRE (350 μm) resolves (only) ~10% of the cosmic infrared background
- → Antarctic 10m surveys: ~30%
- → Antarctic 30m surveys: ~90% (!)

Confusion-limited deep surveys using the Antarctic 30m telescope will resolve most of the cosmic infrared background at 350 μm into discrete sources for the first time

Why short-submm?

- A possible approach: do unbiased survey at λ ~850μm – 1mm band, then do multi-wavelength follow up (at shorter wavelengths)
  - An efficient way for ALMA
- But such long-submm (~850μm – 1mm band) surveys may be biased to lower dust temperature galaxies ➔ do unbiased surveys at both short- and long-submm bands!

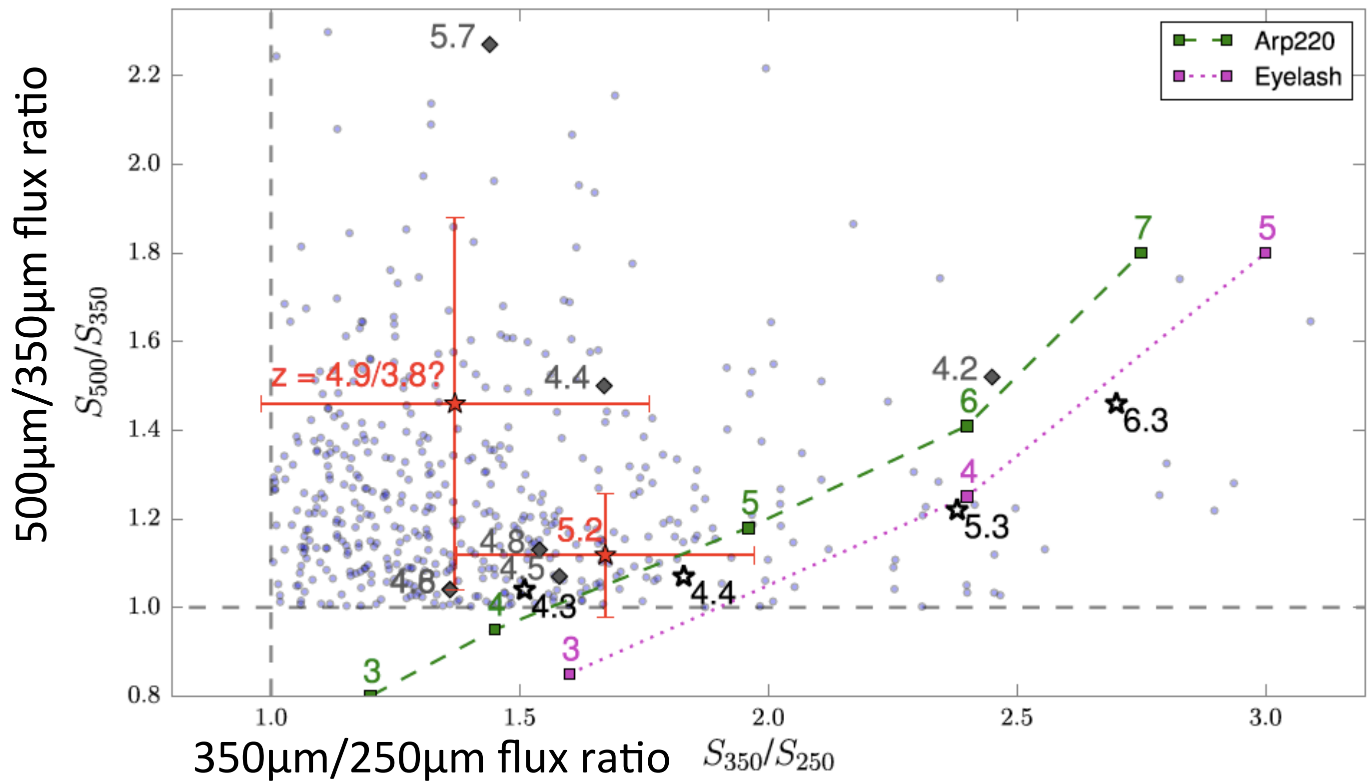


Casay et al. 2013, MNRAS, 436, 1919

How many colors (bands)?

- SPIRE (3 bands) ➔ good estimate of photometric redshifts
- "red SPIRE sources" ➔ promising targets for z > 4 dusty starburst galaxies

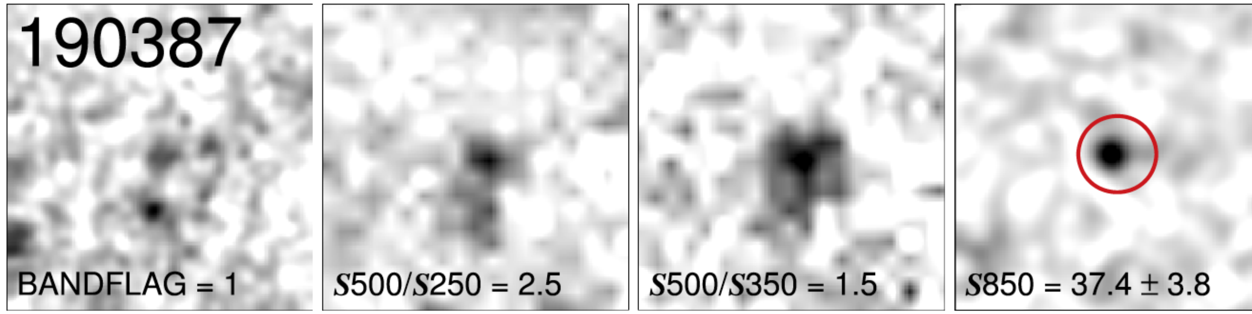
HerMES 274 deg^2
$S_{500}>S_{350}>S_{250}$
5σ cut-off: $S_{500}>52$ mJy
➔ 477 "red" sources



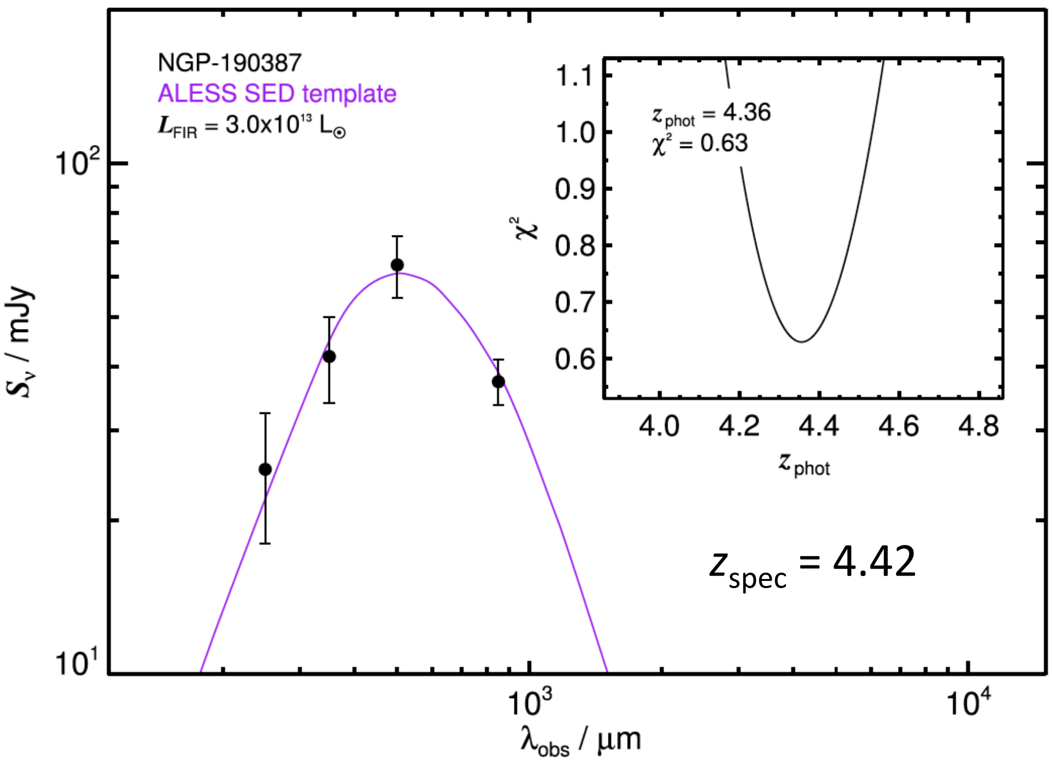
Asboth et al. 2016
MNRAS, 462, 1989

How many colors (bands)?

Ivison et al. 2016, ApJ, 832, 78



250μm 350μm 500μm 850μm (SCUBA2)



- Adding longer wavelength bands ➔ more sensitive for higher redshift dusty galaxies + better redshift constraints

Recommendation:
4 bands @230μm, 350μm, 460μm, and 850μm

Last question:
where is the right place for Antarctic 30-m telescope deep survey?

Synergy
with The South Pole Telescope

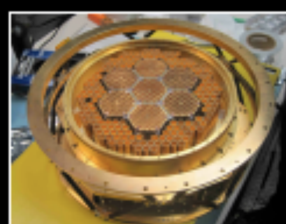
The South Pole Telescope (SPT)

10-meter sub-mm quality wavelength telescope

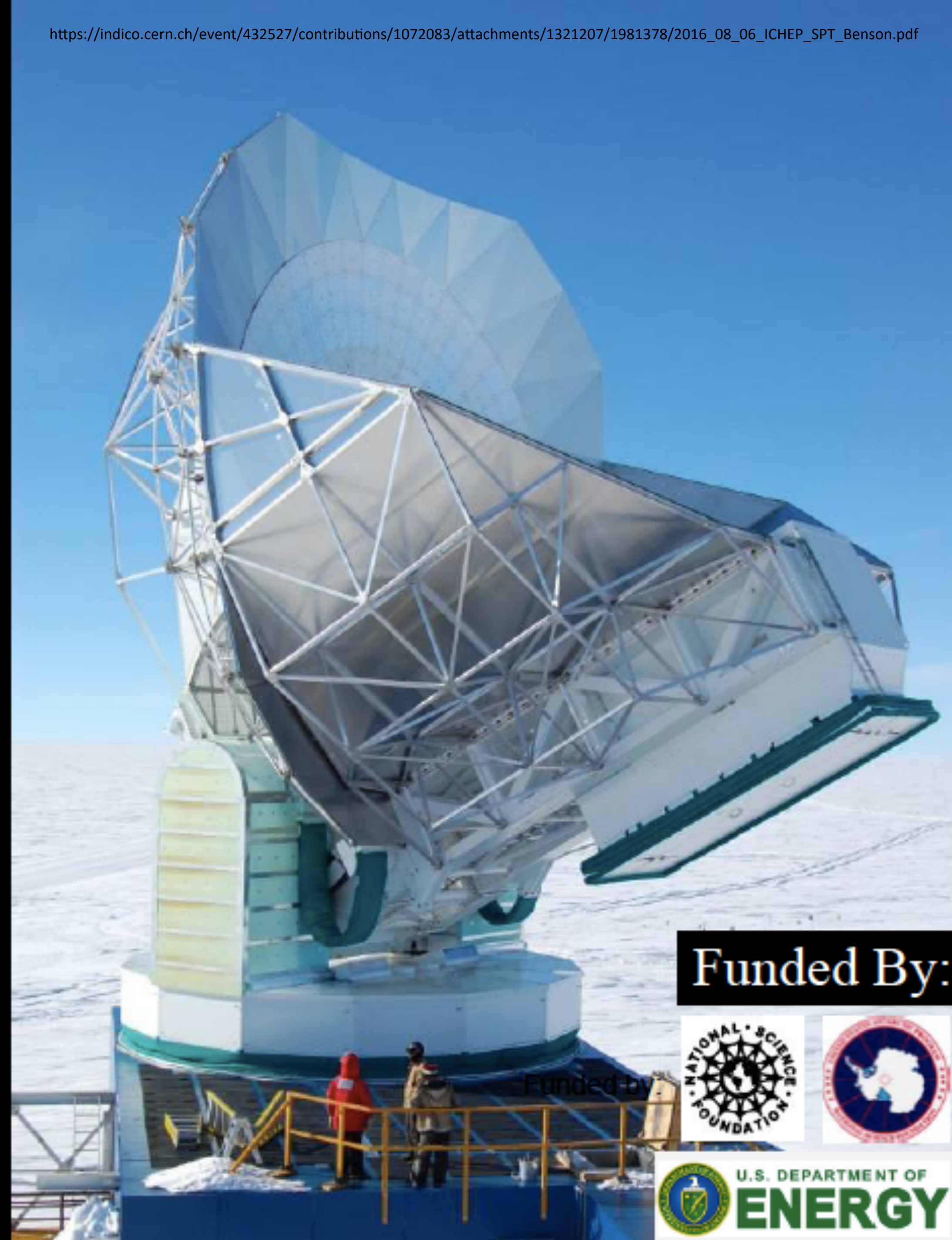
100, 150, 220 GHz and
1.6, 1.2, 1.0 arcmin resolution

2007: SPT-SZ
960 detectors
100,150,220 GHz

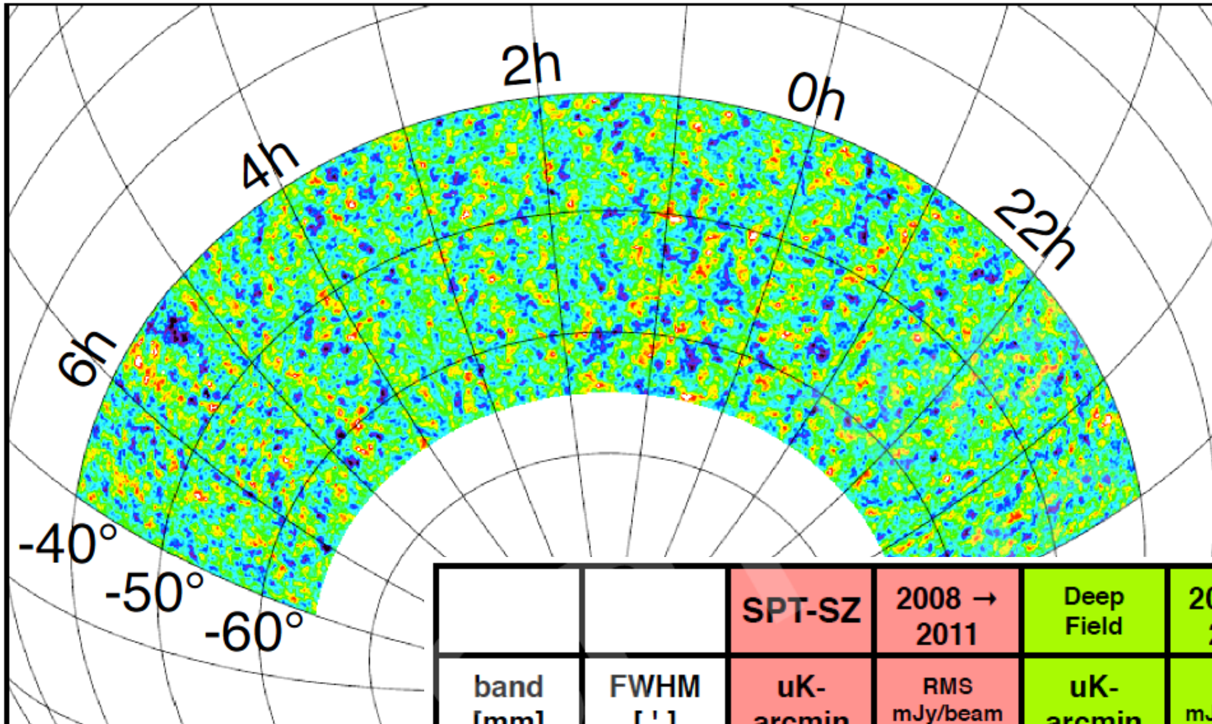
2012: SPTpol
1600 detectors
100,150 GHz
+Polarization

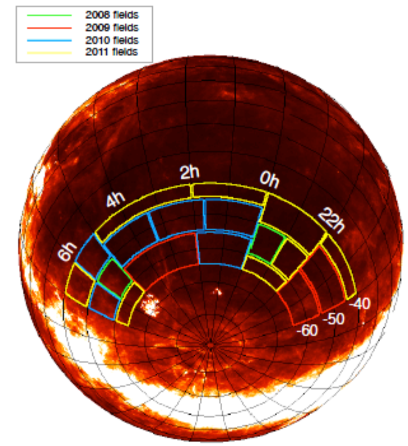


2016: SPT-3G
~16,200 detectors
100,150,220 GHz
+Polarization



SPT 2500 deg^2 (~6% of sky) survey

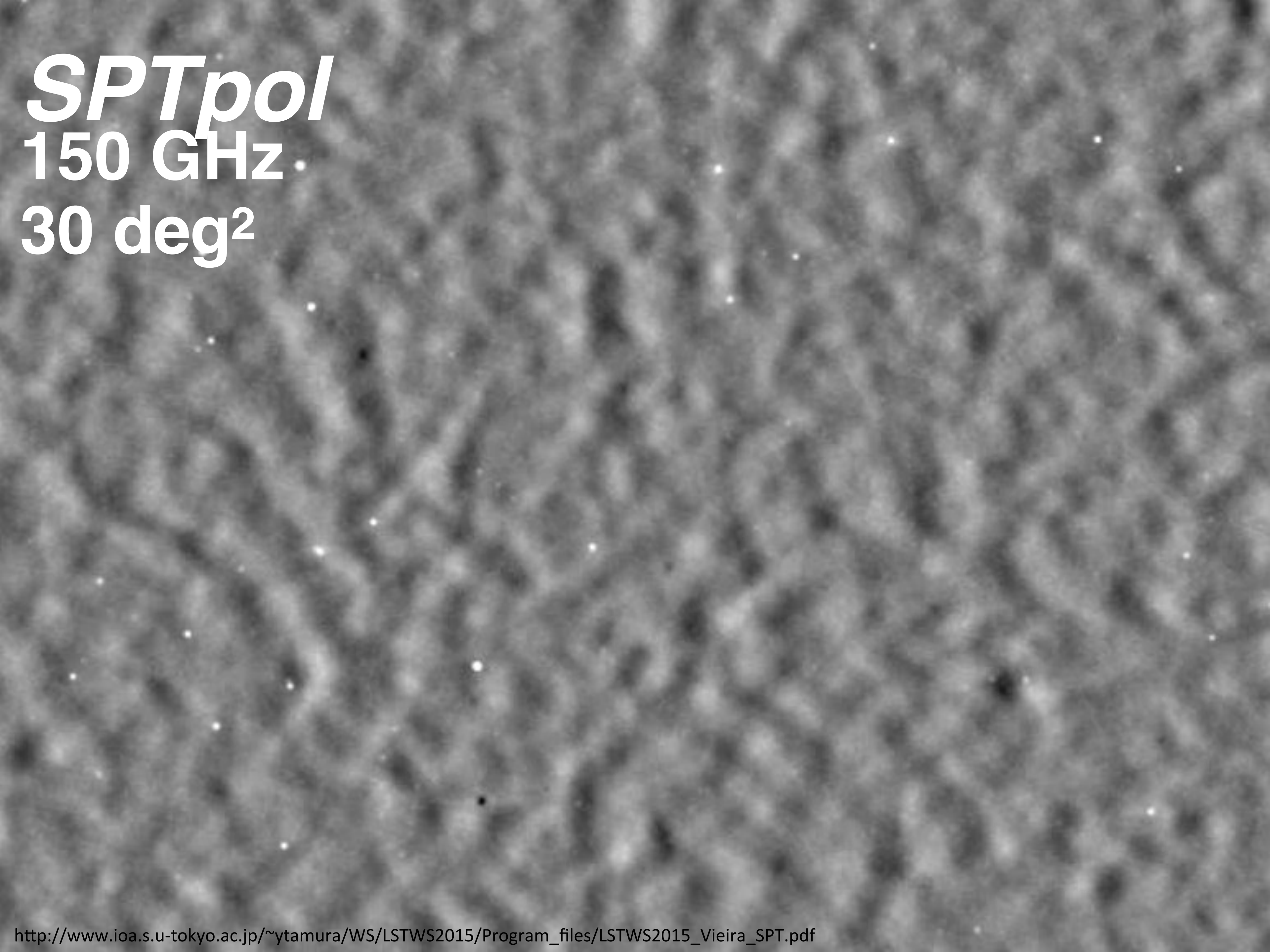




		SPT-SZ	2008 → 2011	Deep Field	2008 → 2011	SPTpol	2012 → 2014	SPT3G	2015 → 2017
band [mm]	FWHM [']	uK-arcmin	RMS mJy/beam	uK-arcmin	RMS mJy/beam	uK-arcmin	RMS mJy/beam	uK-arcmin	RMS mJy/beam
3.0	1.7	42	2.0	42	2.0	6.5	0.3	4.2	0.2
2.0	1.2	18	1.3	13	0.9	4.5	0.3	2.5	0.2
1.4	1.0	85	6.8	35	3.0	--	--	4.0	0.4
area [deg^2]		2500		200		600		2500	

AzTEC/ASTE
1.1mm survey:
30” FWHM
0.4 – 2 mJy (1σ)

http://www.astro.caltech.edu/~vieira/spt_smg_Caltech_public_redacted.pdf



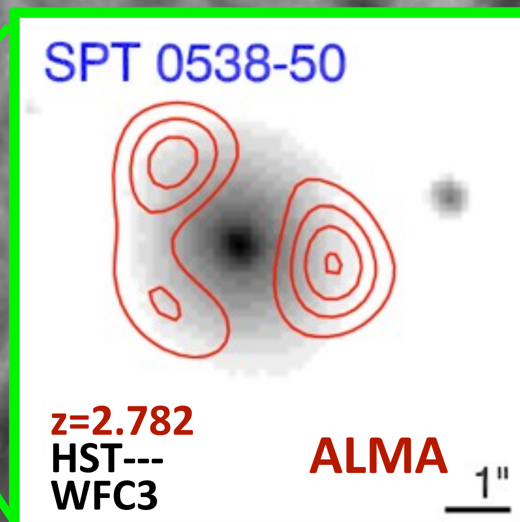
http://www.ioa.s.u-tokyo.ac.jp/~ytamura/WS/LSTWS2015/Program_files/LSTWS2015_Vieira_SPT.pdf

SPTpol

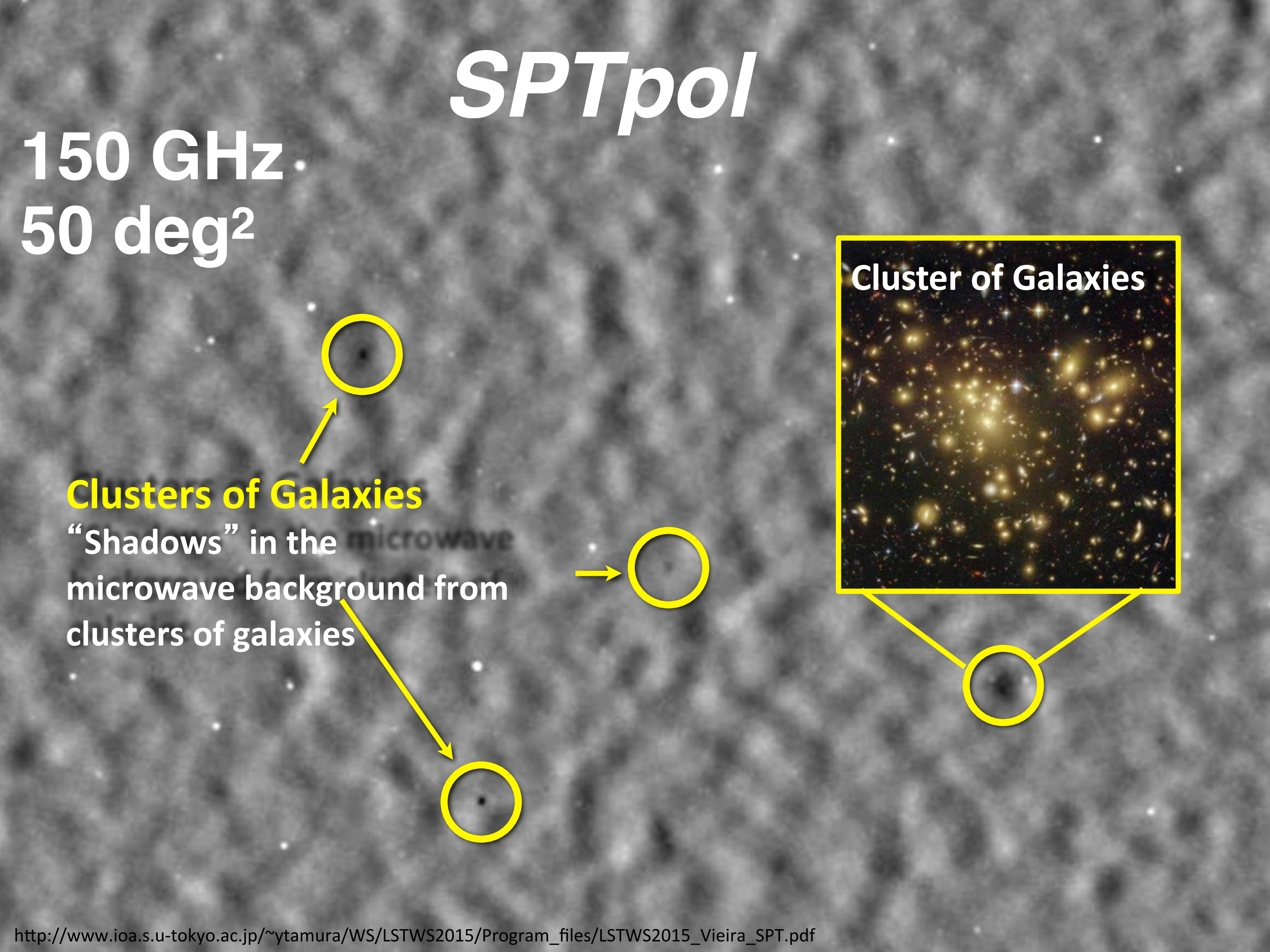
150 GHz
50 deg^2

Point Sources

Ac.ve galac.c nuclei, and the most distant, star---forming galaxies

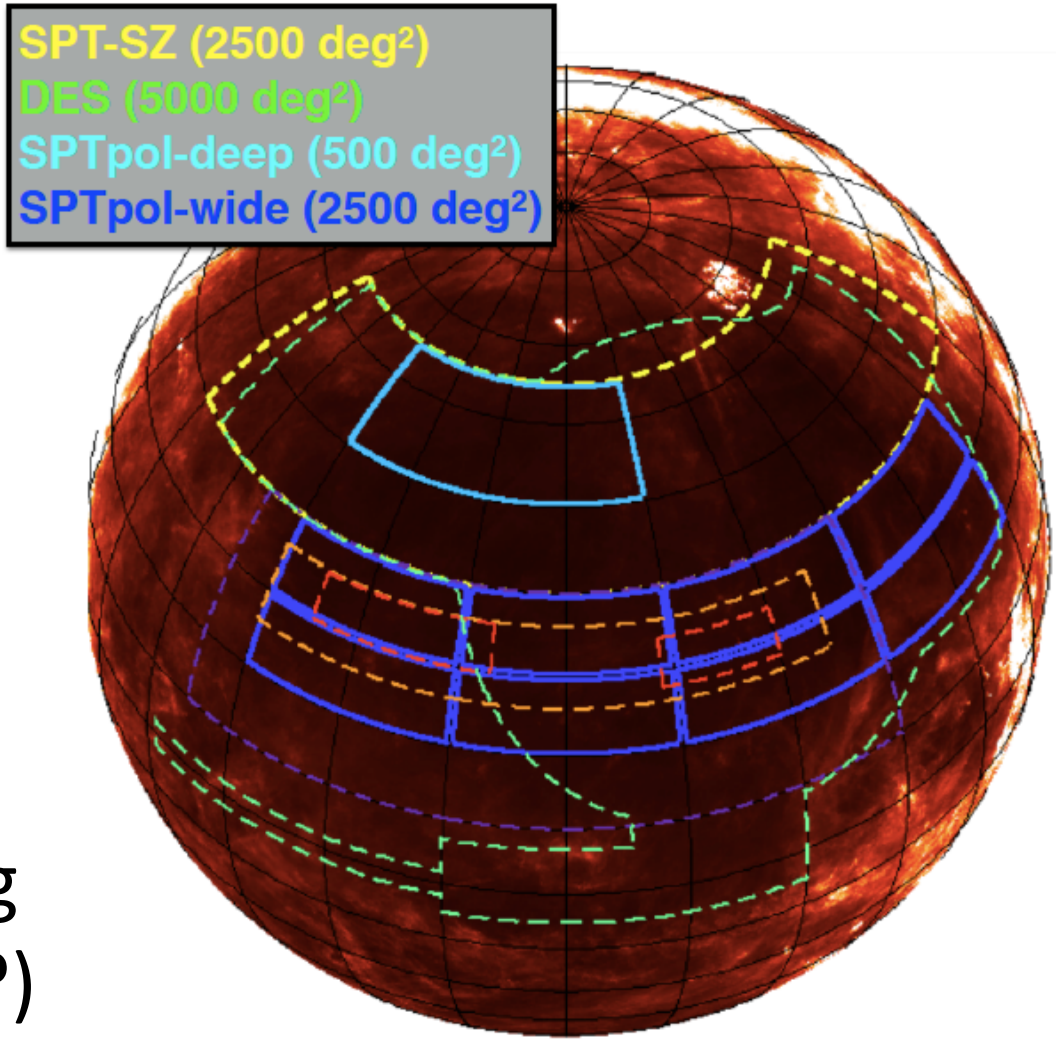


http://www.ioa.s.u-tokyo.ac.jp/~ytamura/WS/LSTWS2015/Program_files/LSTWS2015_Vieira_SPT.pdf


SPTpol
150 GHz
50 deg²
Clusters of Galaxies
"Shadows" in the microwave background from clusters of galaxies
Cluster of Galaxies
http://www.ioa.s.u-tokyo.ac.jp/~ytamura/WS/LSTWS2015/Program_files/LSTWS2015_Vieira_SPT.pdf

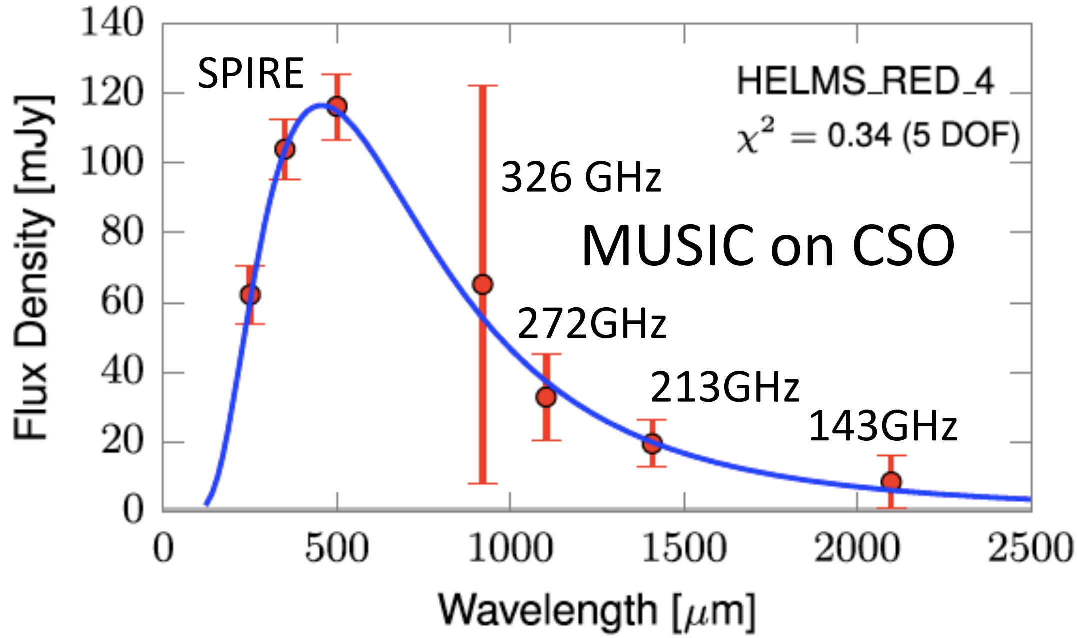
"Wedding-cake" survey strategy

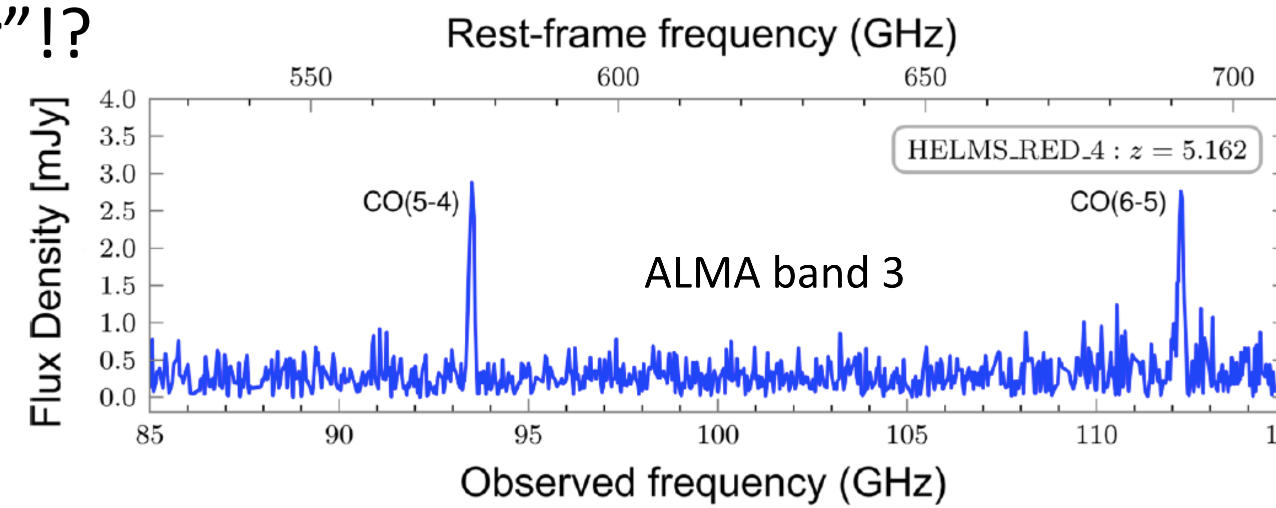
- Widest (and shallowest) survey: SPT 2500 deg^2 area
- Deep survey: SPT-deep 500 deg^2 area
- Ultra-deep survey: ~10 deg^2 area? (where? ➔ targeting SZ-selected clusters?)



Adding SPT bands?

- Adding longer wavelength bands ➔ more sensitive for higher redshift dusty galaxies + better redshift constraints
- Better characterization of "850μm riser"!?
- But 1' beam…





Asboth et al. 2016
MNRAS, 462, 1989

Expected mapping speeds

http://www.px.tsukuba.ac.jp/~nakai/astroobs/pdf/antarctic30m-spec.pdf

南極 30m テラヘルツ望遠鏡－諸元－

（2015.11.2）

○感度等

（1）連続波観測（注 1）

（冬季 50%レベル@新ドームふじ）

	周波数帯	感　度（5 σ rms）　（τ =積分時間）				角分解能	素子数	Mapping speed [deg^2 hr^{-1} mJy^{-2}]
		τ =60sec	1 hour	10 hours	confusion			
850μm	350GHz	0.80mJy	0.10mJy	0.033mJy	0.22 mJy	7.1”	4800×2	44×2
750μm	400	1.12	0.15	0.046	0.20	6.2”	6300×2	22×2
460μm	650	1.68	0.22	0.069	0.052	3.8”	16600×3	9.8×3
350μm	850	2.45	0.32	0.10	0.011	2.9”	27000×2	4.4×2
230μm	1300	13.6	1.76	0.56	0.00035	1.9”	10800×2	0.024×2 (注 3)
200μm	1500	46.4	5.99	1.89	0.00009	1.7”	14400×3	0.0022×3 (同)

（注 1: 点源を観測したときのフラックス密度での感度。感度は$1/\sqrt{\tau}$ に比例する。

（注 2: Confusion limit は Blain+2002 を元に求める）

（注 3: ホーンを使用予定）

500 deg^2 deep survey plan

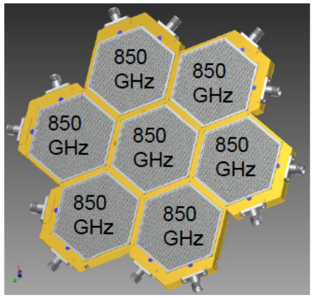
5σ 1 mJy@850μm
➔ L(IR) = $5\times10^{11} L_\odot$@z=5 (Tdust = 30K)
➔ L(IR) = $2\times10^{12} L_\odot$@z=5 (Tdust = 50K)

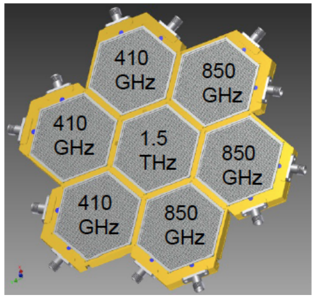
- 850 μm: 44 $deg^2/hr/mJy^2$ x 1 unit
  ➔ 0.2 mJy (1σ) in 280 hrs – confusion limited
- 460 μm: 9.8 $deg^2/hr/mJy^2$ x 1 unit
- ➔ 0.3 mJy (1σ) in 1260 hrs – confusion limited
- 350 μm: 4.4 $deg^2/hr/mJy^2$ x 1 unit
  ➔ 0.2 mJy (1σ) in 2840 hrs – confusion limited
- 230 μm: 0.024 $deg^2/hr/mJy^2$ x 4 unit
  ➔ 1.2 mJy (1σ) in 2890 hrs
  – Not confusion limited, but ~50% (?) of the CIB will be resolved

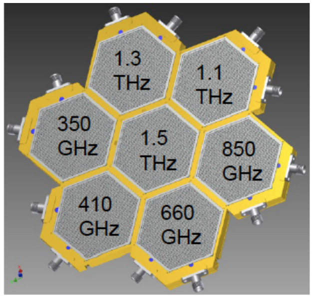
~30x deeper than Herschel surveys

More allocation of 1.3 THz pixels may be considered to equalize mapping speeds among 4 bands

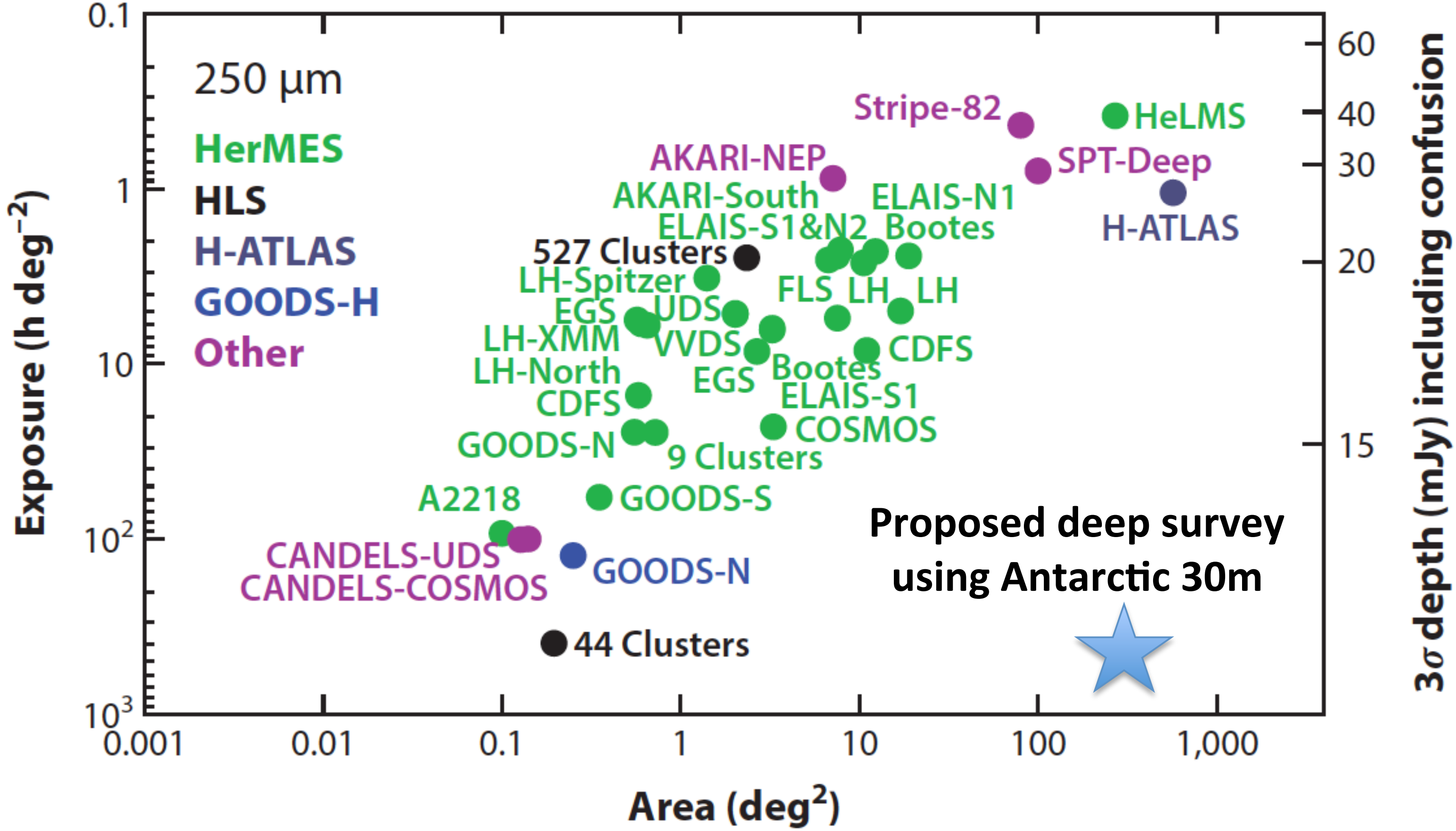
3000 hrs deep survey plan:
- High cadence 850μm survey
 (10 confusion-limited maps will be obtained after the survey) ➔ search for time variable sources







Comparison with previous surveys



Lutz 2014, ARAA, 52, 373

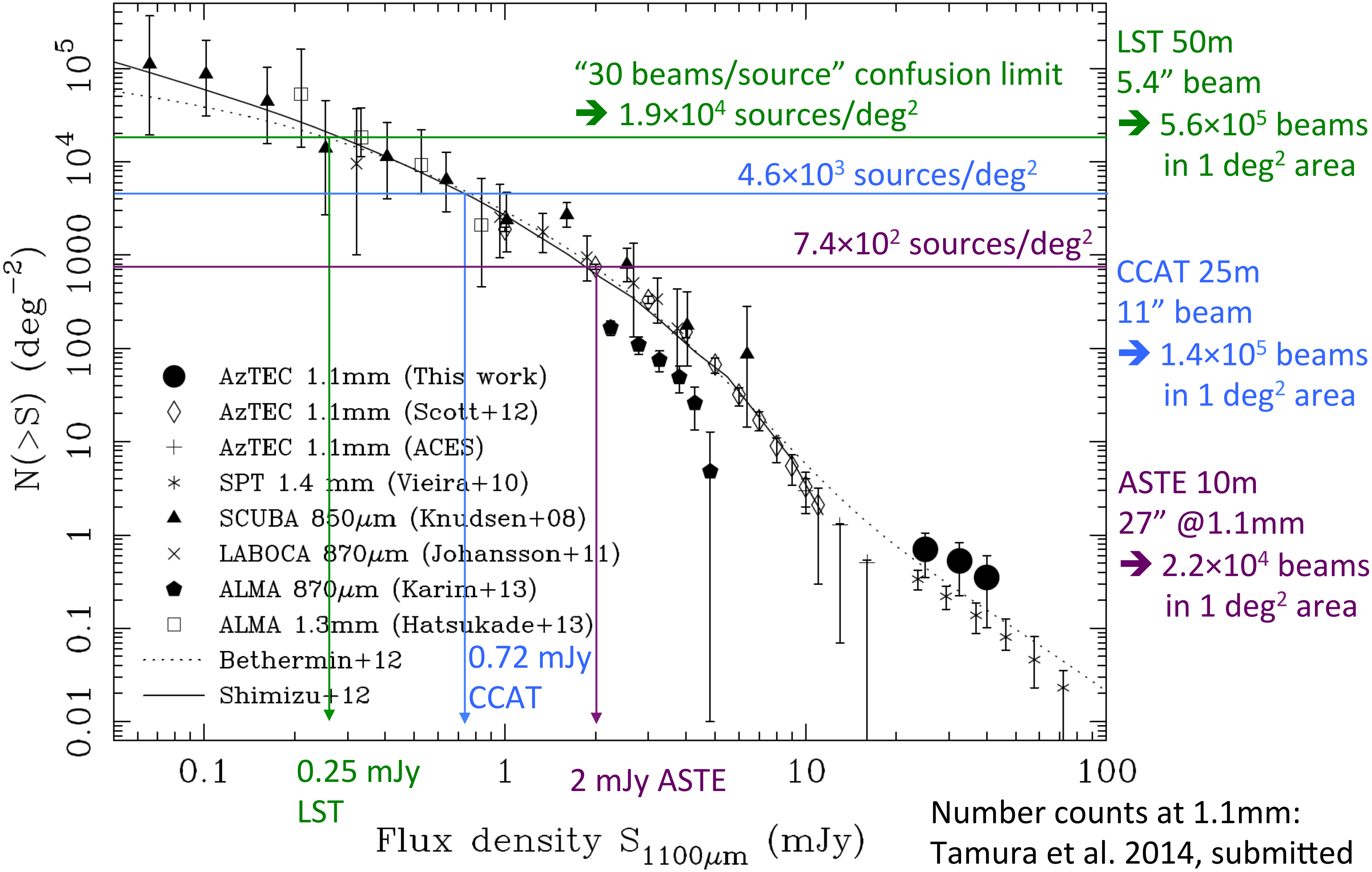
Conclusions (for a deep photometric survey plan)

- Antarctic 30-m terahertz telescope, equipped with 350 GHz, 650 GHz, 850 GHz & 1.3 THz bands (850 μm, 460 μm, 350 μm & 230 μm) ➔ a ~3,000 hrs deep survey at "SPT-deep 500 deg^2 area"
  - Following successful multi-band approach by SPIRE 3 colors + 1 longer photometric point (e.g., SCUBA2 etc.)
  - and deeper than Herschel surveys by a factor of ~30 !
  - Mitigating "low dust temperature bias" of 850 μm – 1 mm single band surveys
  - 350μm band is really unique for a 30-m telescope; the cosmic infrared background at 350μm will be fully resolved into discrete sources for the first time
  - A high cadence (~10 times during the survey period) 850 μm confusion-limited-depth photometric survey will also be implemented automatically.

これまでの検討･今後しなければいけない検討

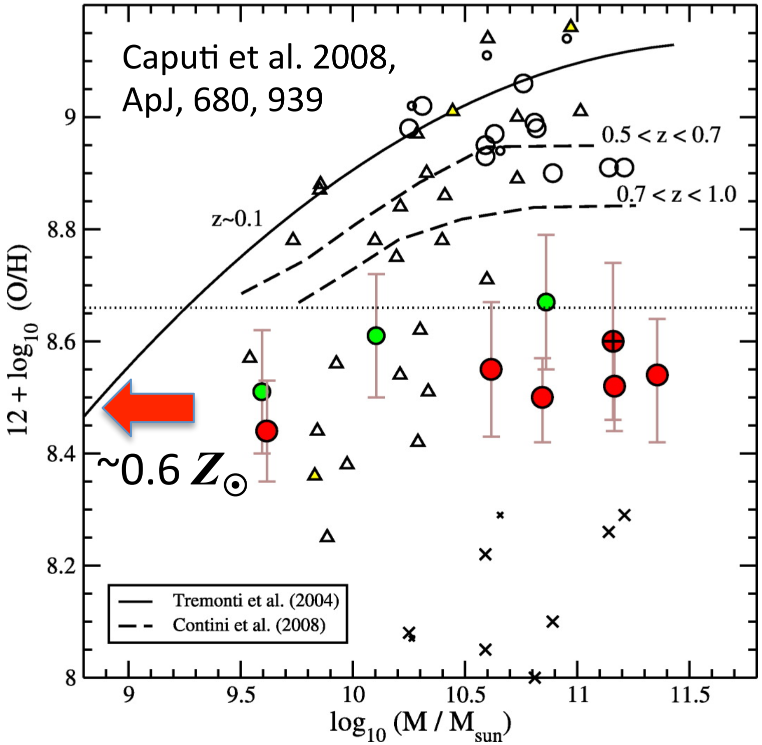
- 装置仕様のドライバーとなるような、目玉となるサイエンスになるかどうかは、またさらに要･議論、として。
- いくつかの候補(これまでの議論)
  - 連続波による銀河探査 ➔ (1) 特に$z > 4$を超えるような時代での、ダストに隠された星形成活動の寄与、(2) AGNにおける高温ダストの探査/熱源切り分け
    - THz/subTHzバンドで行う意義は？
    - Confusion limitのきっちりした調査は？
  - Redshifted H_2
    - まともにやると難しい。でも、すごく強いショックを受けたような領域があればどうか？ Intensity mappingは？
  - Fine structure linesによるダストに隠された領域での金属量診断
- まだあまり検討できていない候補は？
  - 無バイアス輝線銀河探査 ➔ [CII] or [OIII] tomography !?
  - OH P-Cyg profileの系統的な探査 ➔ AGN feedback
  - CH^+ absorptionの系統的な探査 ➔ large scale turbulence ➔ (caused by what??)

Consistency with measured number counts: Confusion limit at 270GHz/1.1mm

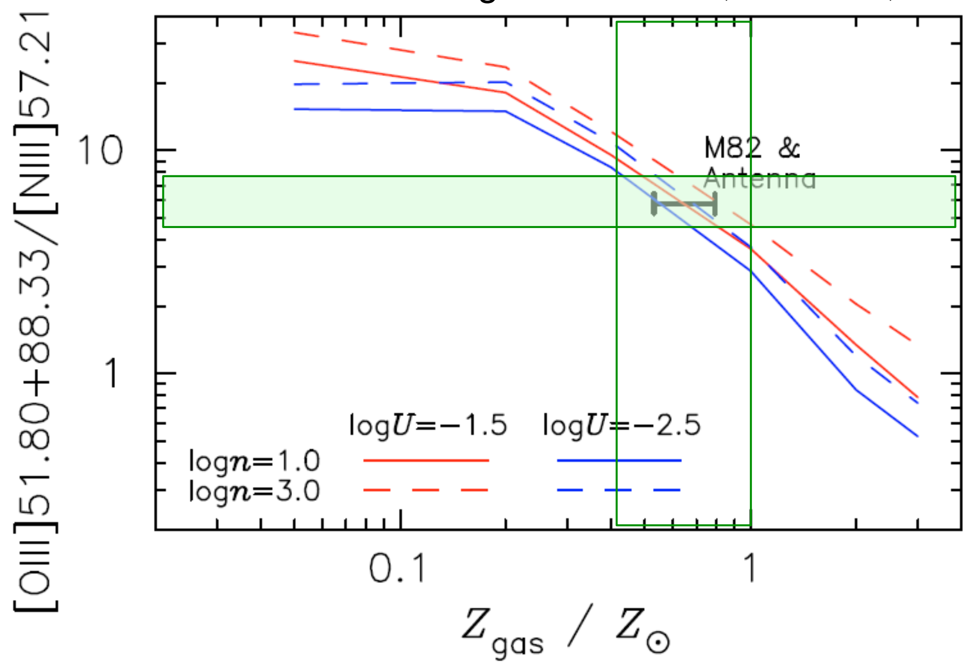


Number counts at 1.1mm: Tamura et al. 2014, submitted

遠赤外スペクトル線の強度比で探る ダストに埋もれた超大光度赤外銀河での金属量

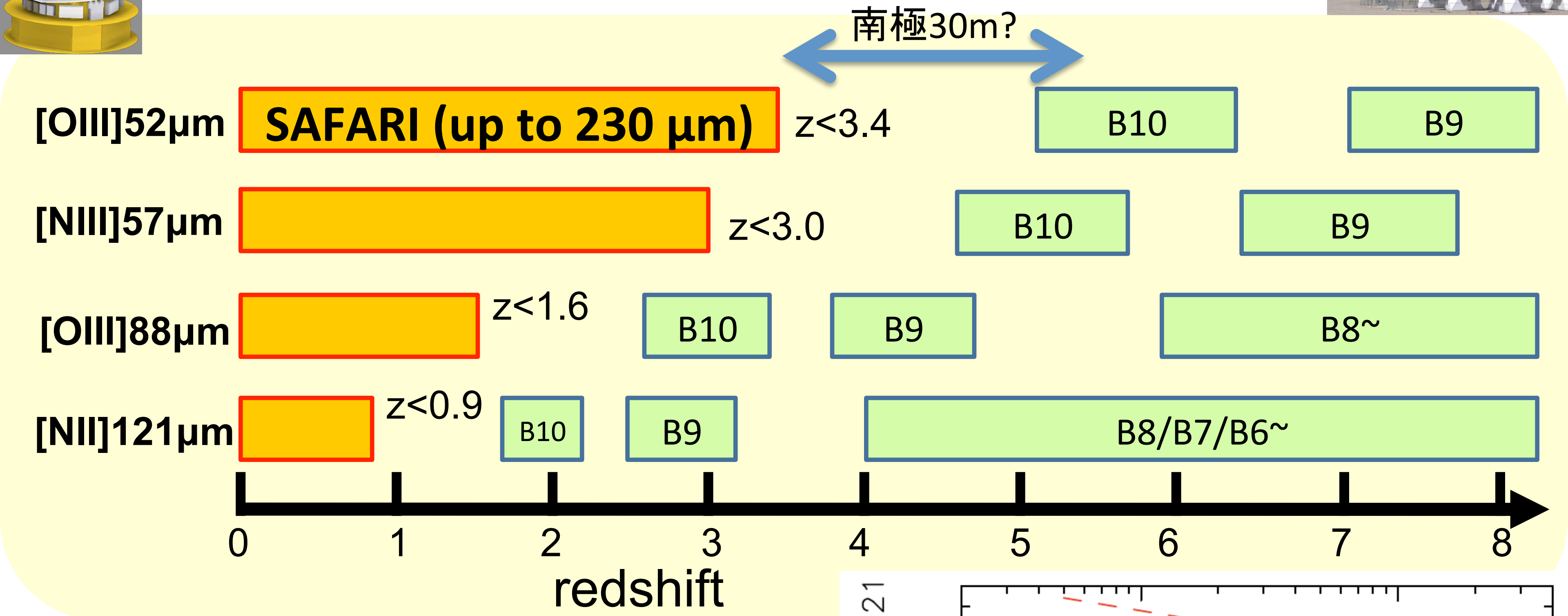


Nagao et al. 2011, A&A 526, A149

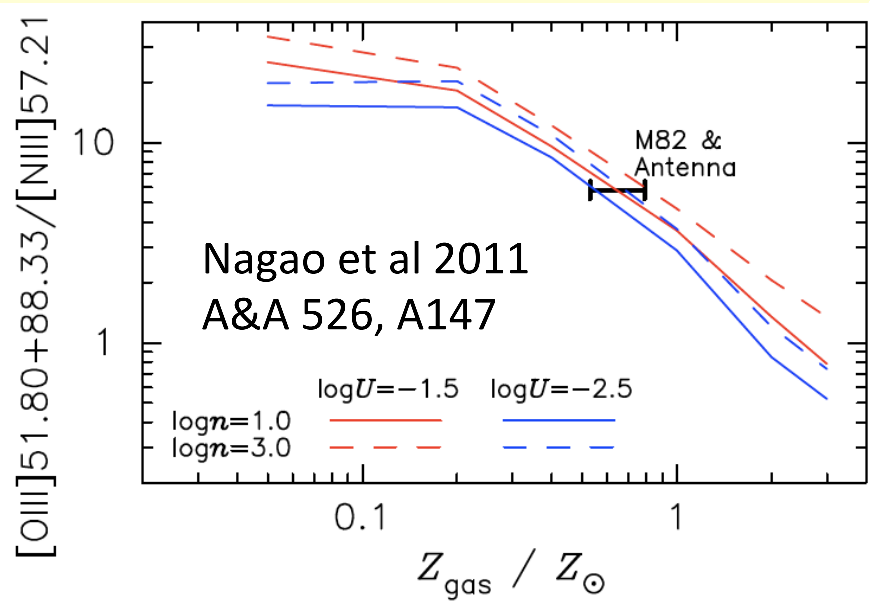


- 可視域の輝線比で診断すると、ULIRGは金属量が低いことが示唆される。➔降着中の「若い」ガスを見ている？それとも、ダストで深い吸収を受けているため、可視域の診断では、金属量勾配の「裾」しか見えていない？（大きな課題）
- ([OIII]51.80+[OIII]88.33)/[NIII]57.21強度比が測定できる赤方偏移の銀河であれば、より正確な金属量の診断が可能。（z<1.3）
- 各輝線がS/N=5であっても、可視輝線診断で示唆されるような低金属量（sub-solar）なのかどうかの判定が可能。

Fine structure lines



- Combination of SAFARI/SPICA and ALMA band 10 allows us to calibrate the proposed metallicity indicator ([OIII]52μm/[NIII]57μm ratio) by adding [OIII]88μm line at z~3.
- It also gives a basis for extension of the method to galaxies at z~5 and beyond.



ALMA [OIII] 88μm detection at z=7.21

Inoue, A., Tamura, Y., KK et al. 2016, Science

f(obs) = 413 GHz (Band8), 41 antennas, 2 hours (on-source)

0.45" x 0.38" resolution (NA)

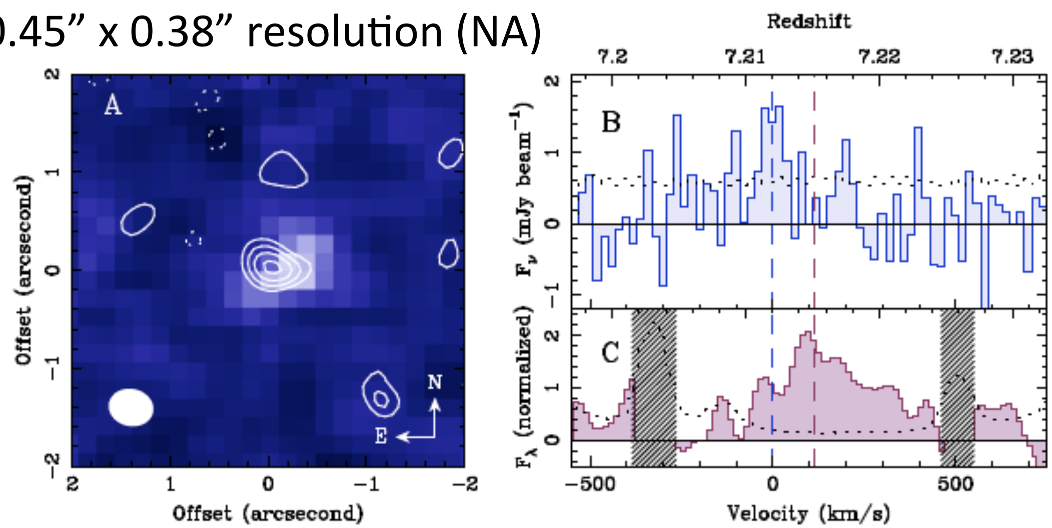
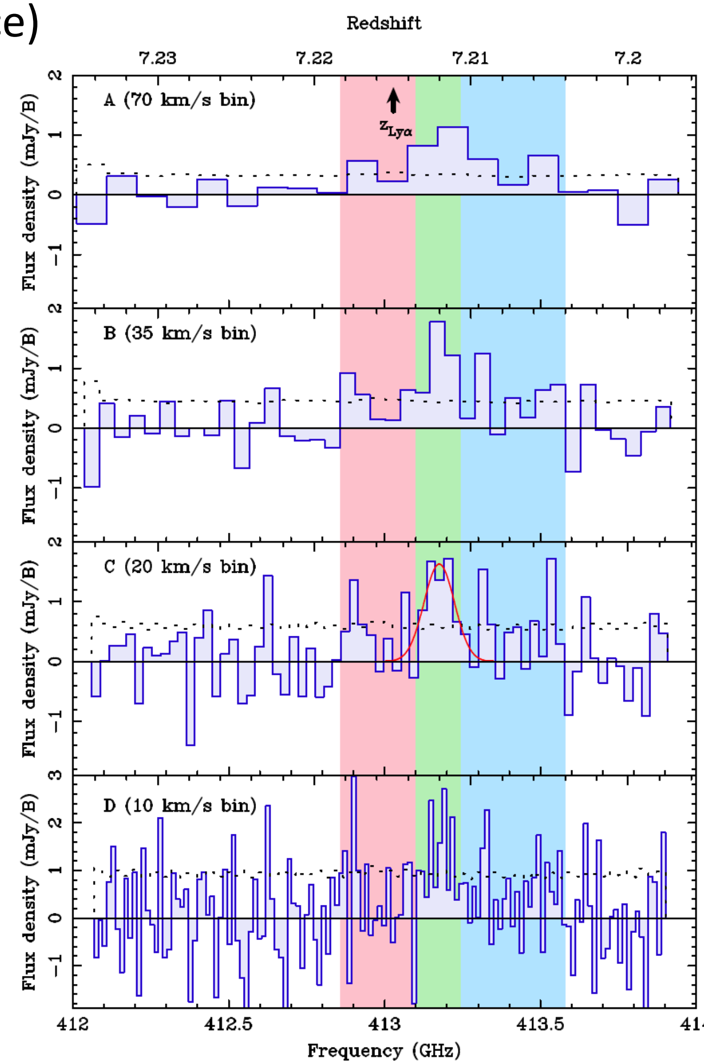


Figure 1: [O III] 88 μm and Lyα emission images and spectra of SXDF-NB1006-2. (A) The ALMA [O III] 88 μm image (contours) overlaid on the Subaru narrow-band Lyα image (**offsets from the position listed in Table 1**). Contours are drawn at $(-2, 2, 3, 4, 5)\times\sigma$, where $\sigma = 0.0636$ Jy beam^{-1} km s^{-1}. Negative contours are shown by the dotted line. The ellipse at the bottom-left corner represents the synthesized beam size of ALMA. (B) The ALMA [O III] 88 μm spectrum with a 20 km s^{-1} resolution shown against the relative velocity with respect to the redshift $z = 7.2120$ (blue dashed line). The r.m.s. noise level is shown by the dotted line. (C) The Lyα spectrum (*17*) shown as a function of the relative velocity compared to the [O III] 88 μm line. The flux density is normalized by a unit of 10^{-18} erg s^{-1} cm^{-2} Å^{-1}. The sky level on an arbitrary scale is shown by the dotted line. The velocity intervals where OH air-glow lines severely contaminate the spectrum are flagged (hatched boxes). **The Lyα line shows a velocity shift $\Delta v = +111$ km s^{-1} relative to the [O III] line (red dashed line).**



Elevated $L_{[OIII]88\mu m}/L_{[CII]158\mu m}$ and $L_{[OIII]}/L_{TIR}$ ratios

Local dwarf galaxies ○

(Madden et al. 2013; De Looze et al. 2014; Cormier et al. 2015)

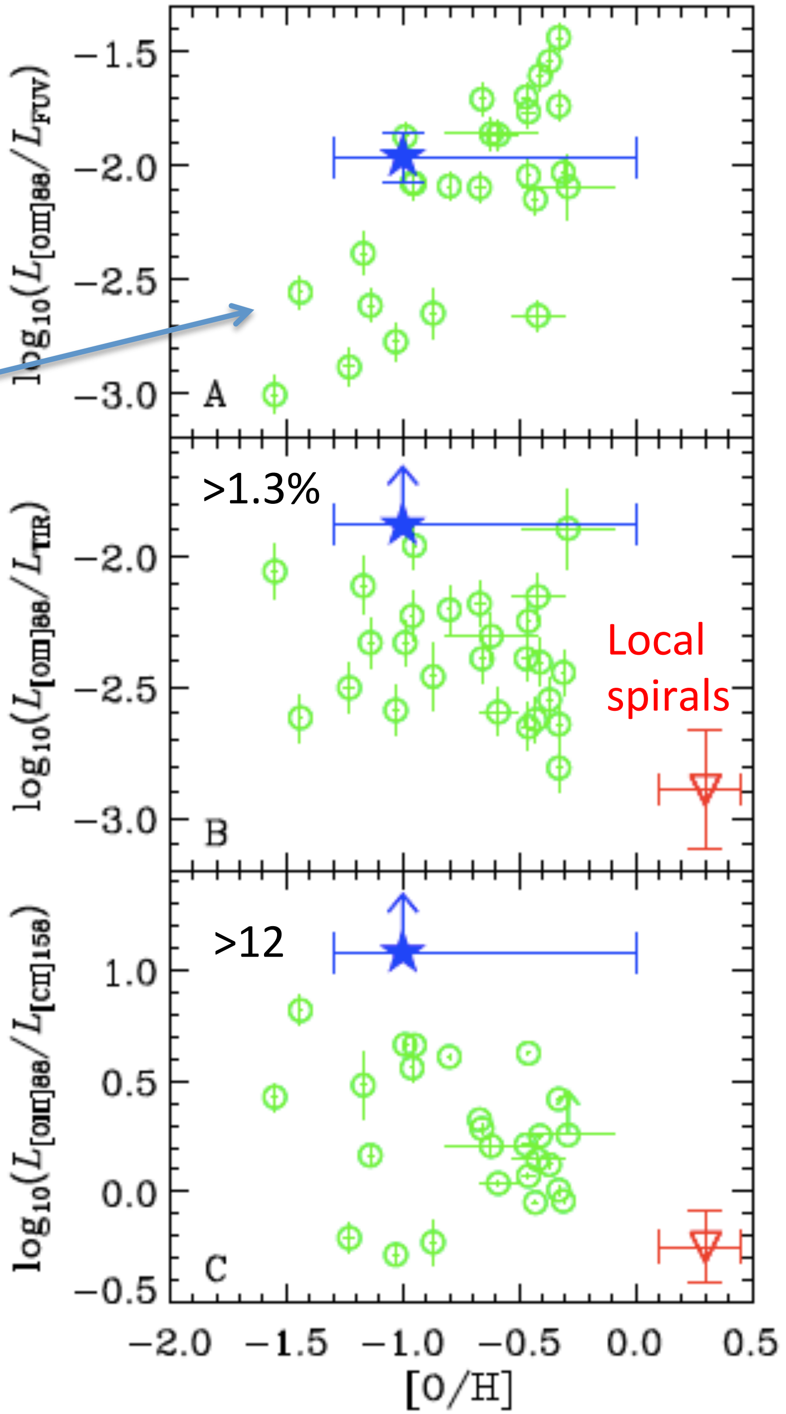
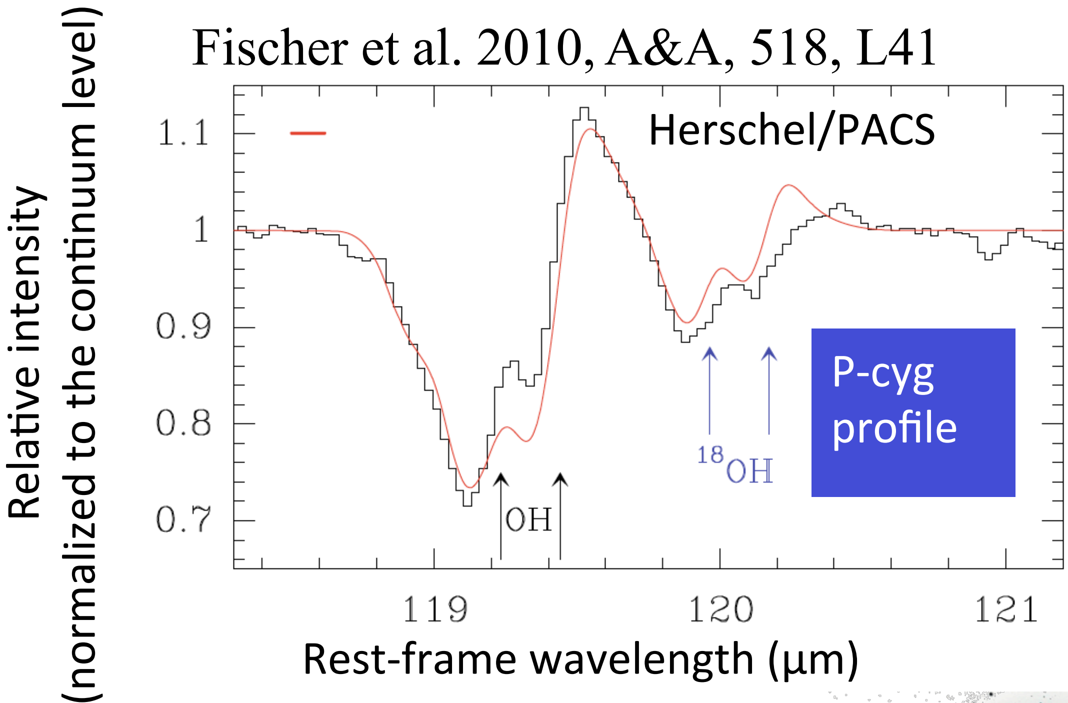


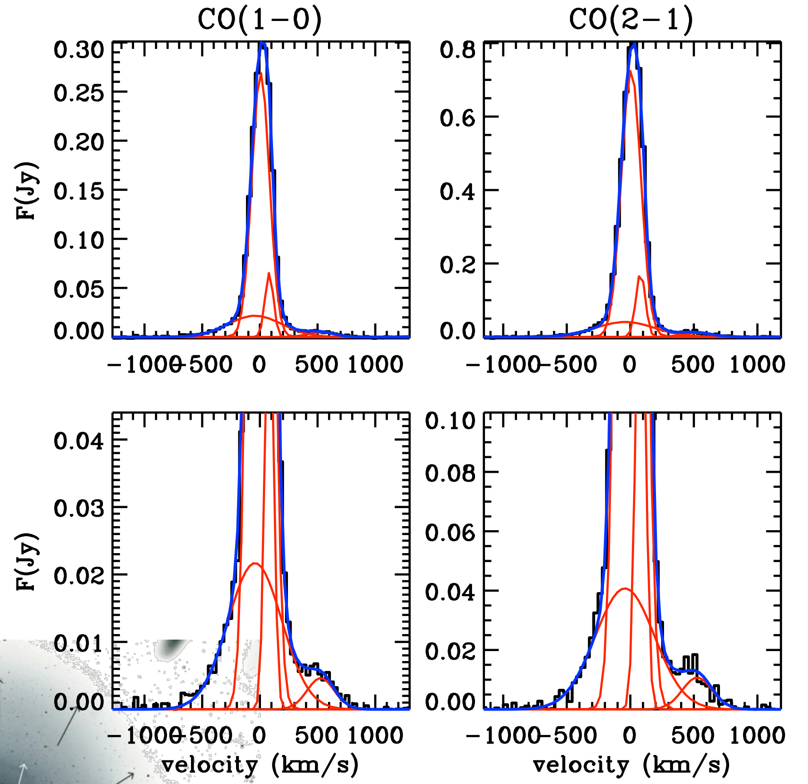
Figure 3: **Comparisons of SXDF-NB1006-2 and nearby galaxies.** The horizontal axis represents the oxygen abundance relative to the Sun on a logarithmic scale: $[O/H] = \log_{10}(n_O/n_H) - \log_{10}(n_O/n_H)_\odot$, where n_O and n_H are the number density of oxygen and hydrogen atoms and the Solar abundance is assumed to be $12 + \log_{10}(n_O/n_H)_\odot = 8.69$ (*30*). The circles with error-bars represent the data of nearby dwarf galaxies (*9–11*) and the inverse triangles with error-bars are averages of nearby spiral galaxies (*13*). SXDF-NB1006-2 is the five-pointed stars with error-bars. (**A**) The [O III]-to-far ultraviolet (FUV) luminosity ratio. The FUV luminosity is νL_ν at about 1500 Å in the source rest-frame. (**B**) The [O III]-to-total infrared (IR) luminosity ratio. The IR wavelength range is 8–1000 μm in the source rest-frame. Since the IR continuum of SXDF-NB1006-2 is not detected, we show a 3σ lower limit with a dust temperature of 40 K and an emissivity index of 1.5. (**C**) The [O III]-to-[C II] luminosity ratio. Since the [C II] 158 μm line of SXDF-NB1006-2 is not detected, we show a 3σ lower limit.

Inoue, A., Tamura, Y., KK et al. 2016, Science http://hubblesite.org/gallery/album/exotic/black_hole/pr2015031b/

Detection of molecular outflows in the local quasar Mrk 231

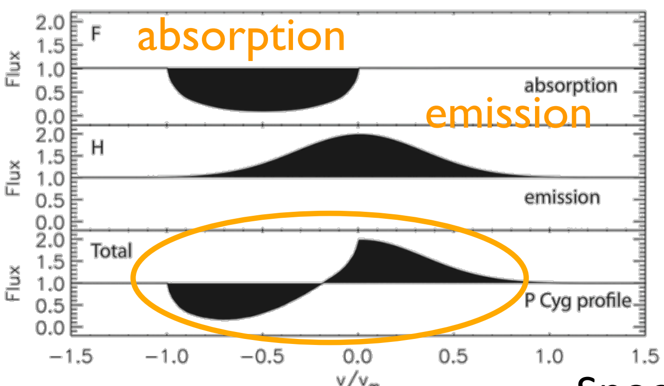
Fischer et al. 2010, A&A, 518, L41

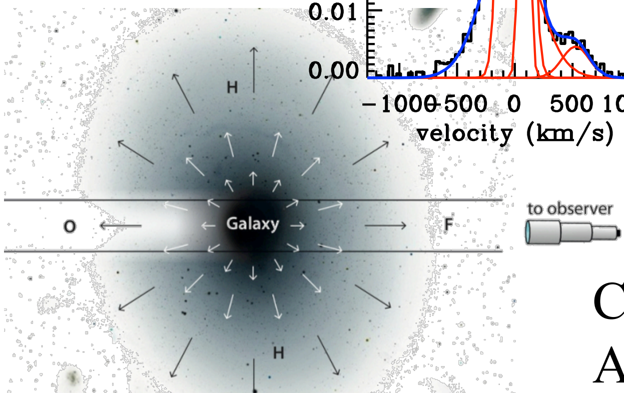




IRAM 30m

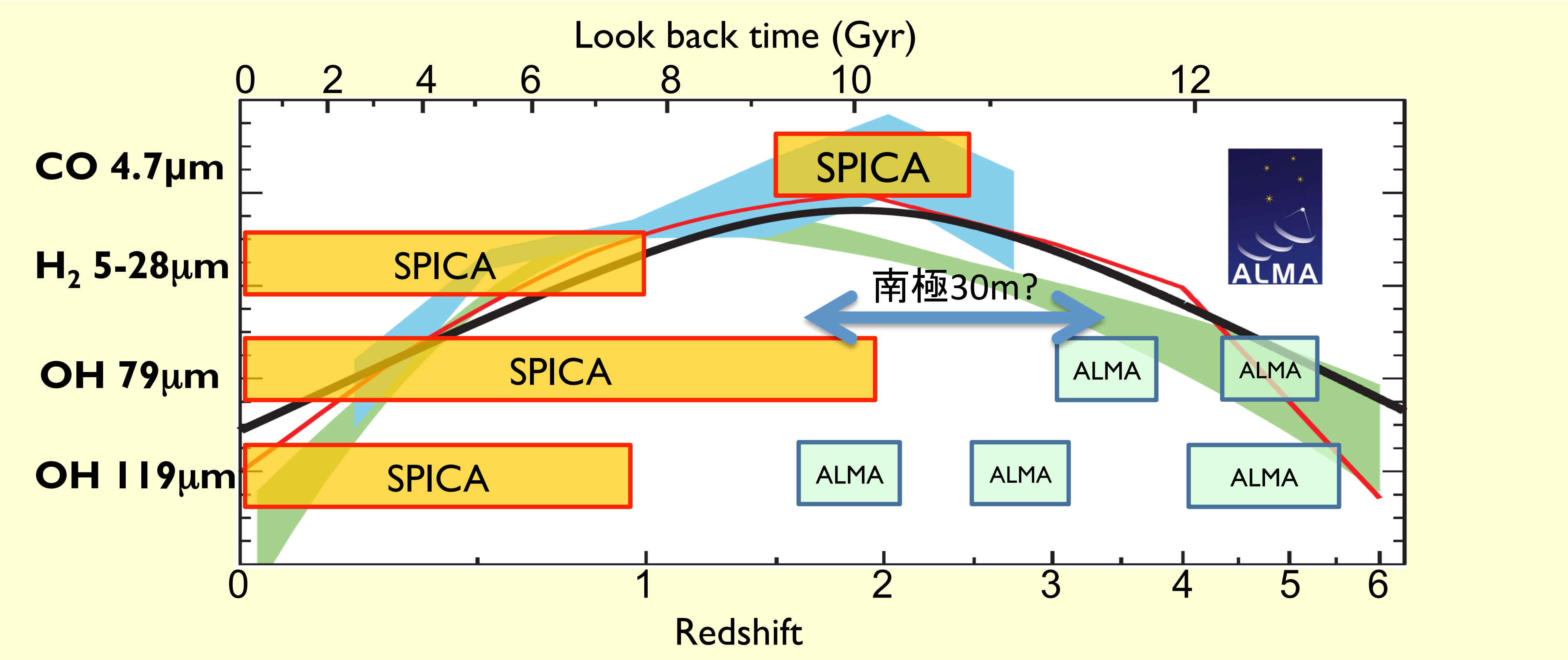
Cicone et al. 2012, A&A, 543, 99

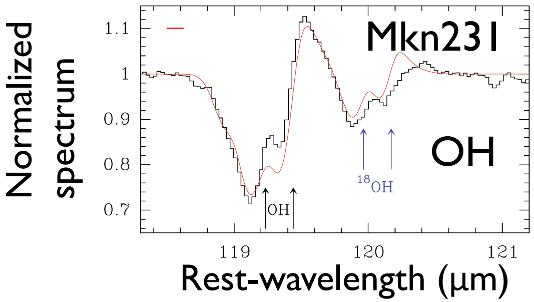




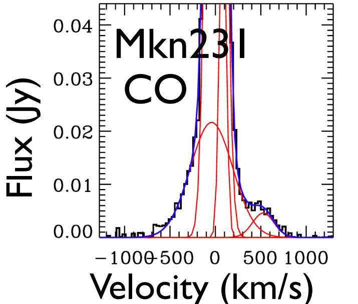
Spoon 2013, ApJ, 775, 127

AGN feedback via OH absorption lines





- ALMA will have a complementary redshift coverage for study of AGN feedback via OH P-Cyg profile
- High velocity wings in CO (and other molecules) with ALMA will also help



CH^+: a unique tracer of dissipative processes

J=1-0
@835.08GHz

- Fast destruction by collisions with H and H_2
- Once formed, its lifetime is short: t ~ 1 yr (!)
  - For n_H = 50 cm^{-3}, f_{H2} = 1
- にもかかわらず、太陽近傍のcold diffuse gasでは豊富 (70年来のpuzzle?)
  - UV-driven chemistryでは1桁以上足りない
  - (fast destructionに打ち克つには) supra-thermal processesによるwarm chemistryが必須
  - Shocks and/or intense velocity shearsによるturbulenceの散逸が重要 (turbulent energy fluxの10^{-2}~10^{-3}程度で充分)

Falgarone et al. 2015, ASP Conf. Sor, Vol. 499

CH+ @SDP17b (z=2.305)

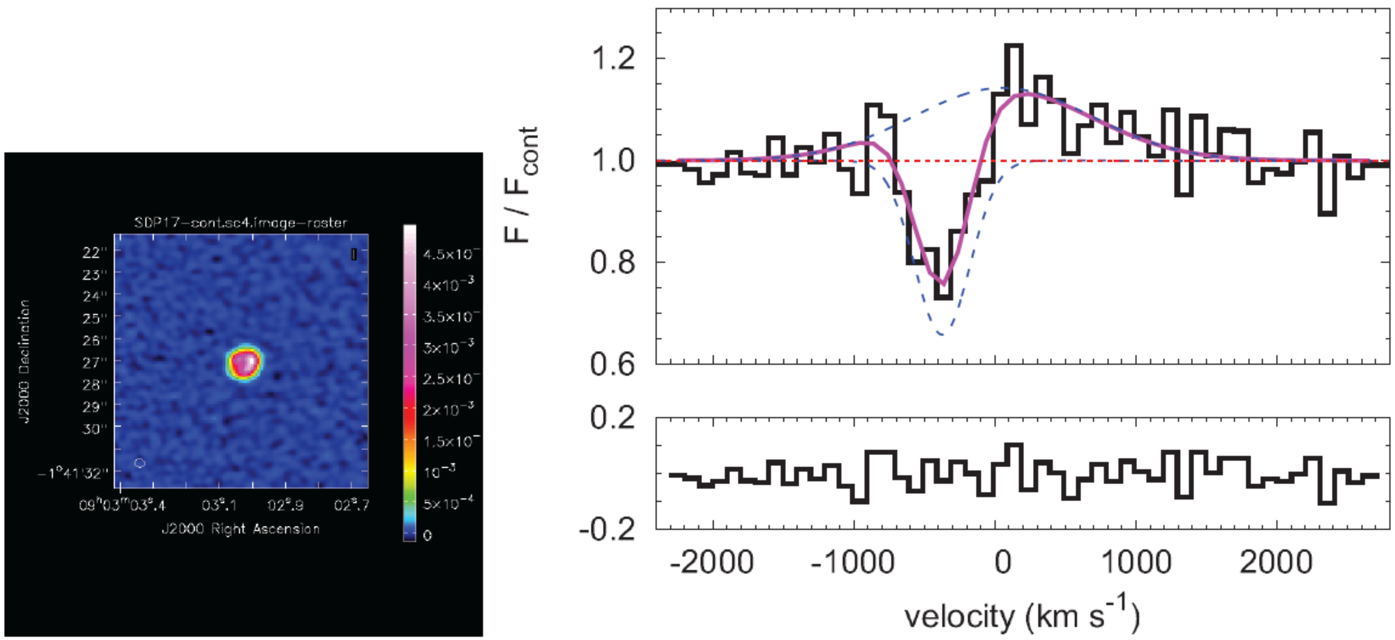


Figure 2. *(Left) ALMA λ 350μm lensed continuum image of SDP17b, (Right)* $^{12}CH^+$*(1-0) spectrum integrated over the fraction of the continuum size where emission is the brightest. Gaussian fits to the emission and absorption lines are shown. The fit residuals are displayed in the bottom frame. The velocity scale is centered at z=2.3051. The observation frequency was ν = 252.66133GHz.*

Falgarone et al. 2015, ASP Conf. Sor, Vol. 499

CH+ @SDP17b (z=2.305)

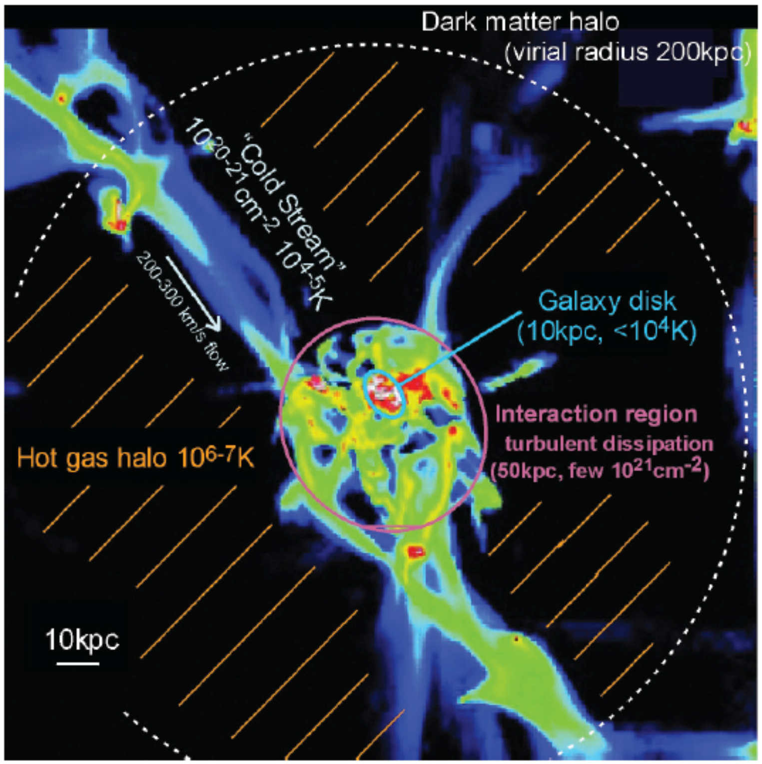


Figure 1. *Sketch of the regions discussed in the text, superposed on cold gas surface densities drawn from the numerical simulations of Gabor et al. (2014): the dark matter (DM) halo filled with hot gas, infalling cold streams, the star-forming galaxy (SFG) disk and the large turbulent interaction region. In the case of SDP17b, the galaxy disk radius is* $r_{1/2}$ = *3kpc. The* CH^+ *absorption line against the dust continuum emission of the SFG probes the front part of the turbulent region (TR), along the narrow solid angle subtended by* $r_{1/2}$.

Falgarone et al. 2015, ASP Conf. Sor, Vol. 499

今後のA/I

- 検討すべき具体的な項目の整理
- 宿題を割り振りたい。。
- Sub WGの設定？？
- 検討が概ねまとまったところで執筆作業開始？
  - いつ・・？