Dust and gas in distant cluster galaxies with ALMA

Eelco van Kampen

ALMA

The design of ALMA is driven by three key science goals:

- The ability to detect spectral line emission from CO or [CII] in a normal galaxy like the Milky Way at a redshift of z=3, in less than 24 hours,
- The ability to image the gas kinematics in protostars and in protoplanetary disks around young Sun-like stars in the nearest molecular clouds (150 pc),
- The ability to provide precise high dynamic range images at an angular resolution of 0.1 arcsec.

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cluster

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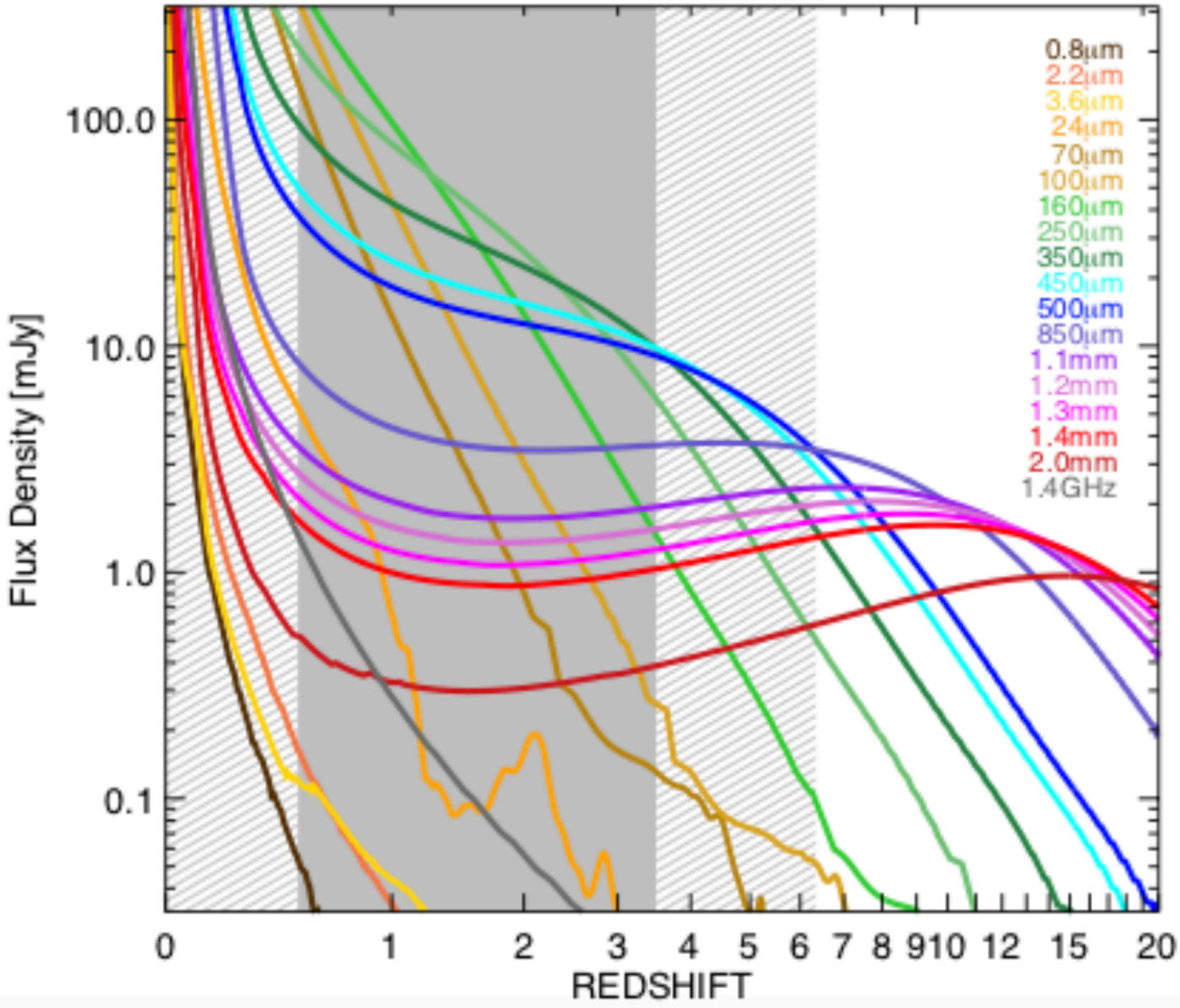
ALMA all the way ….

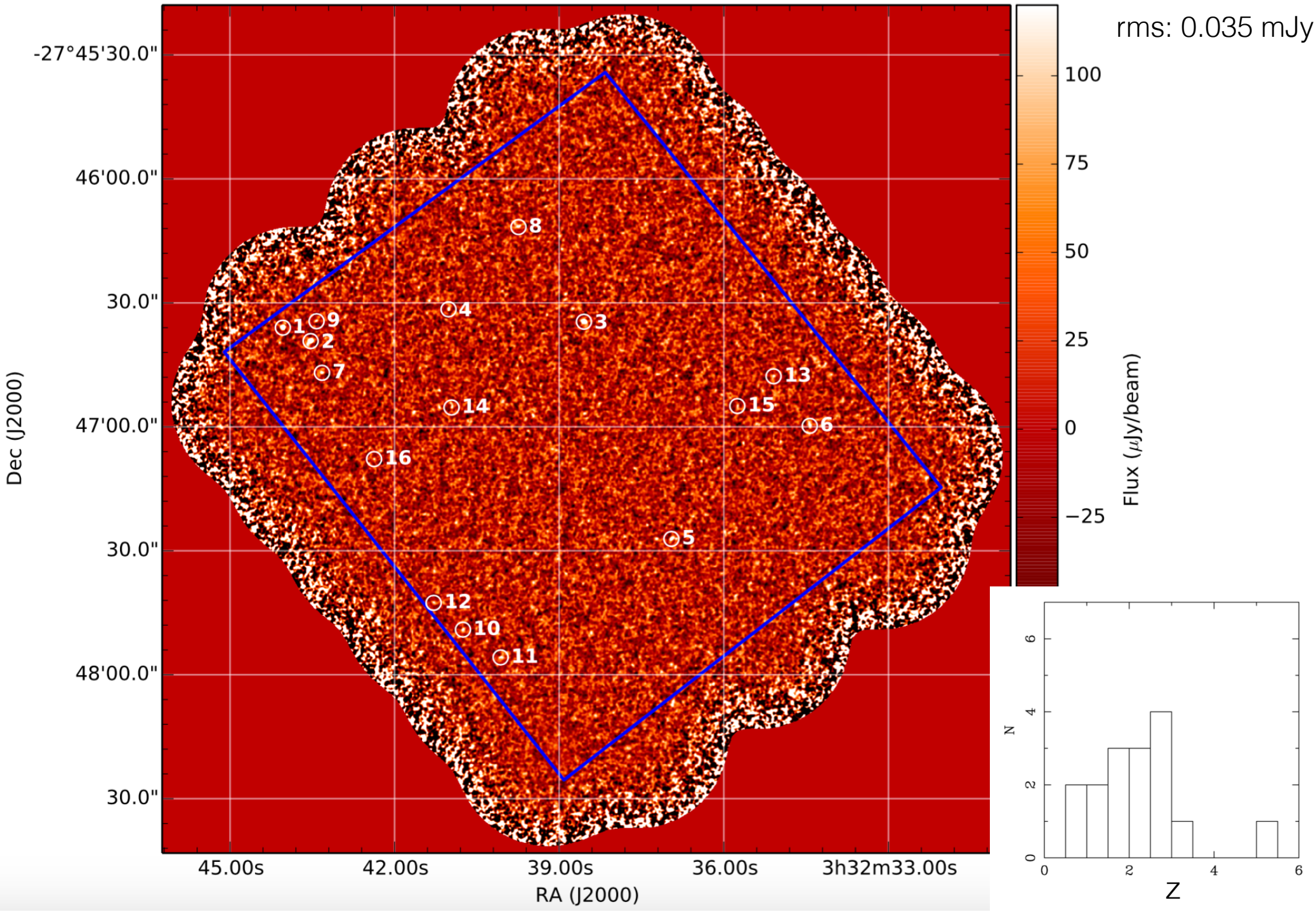


Very strong negative K-correction for continuum emission

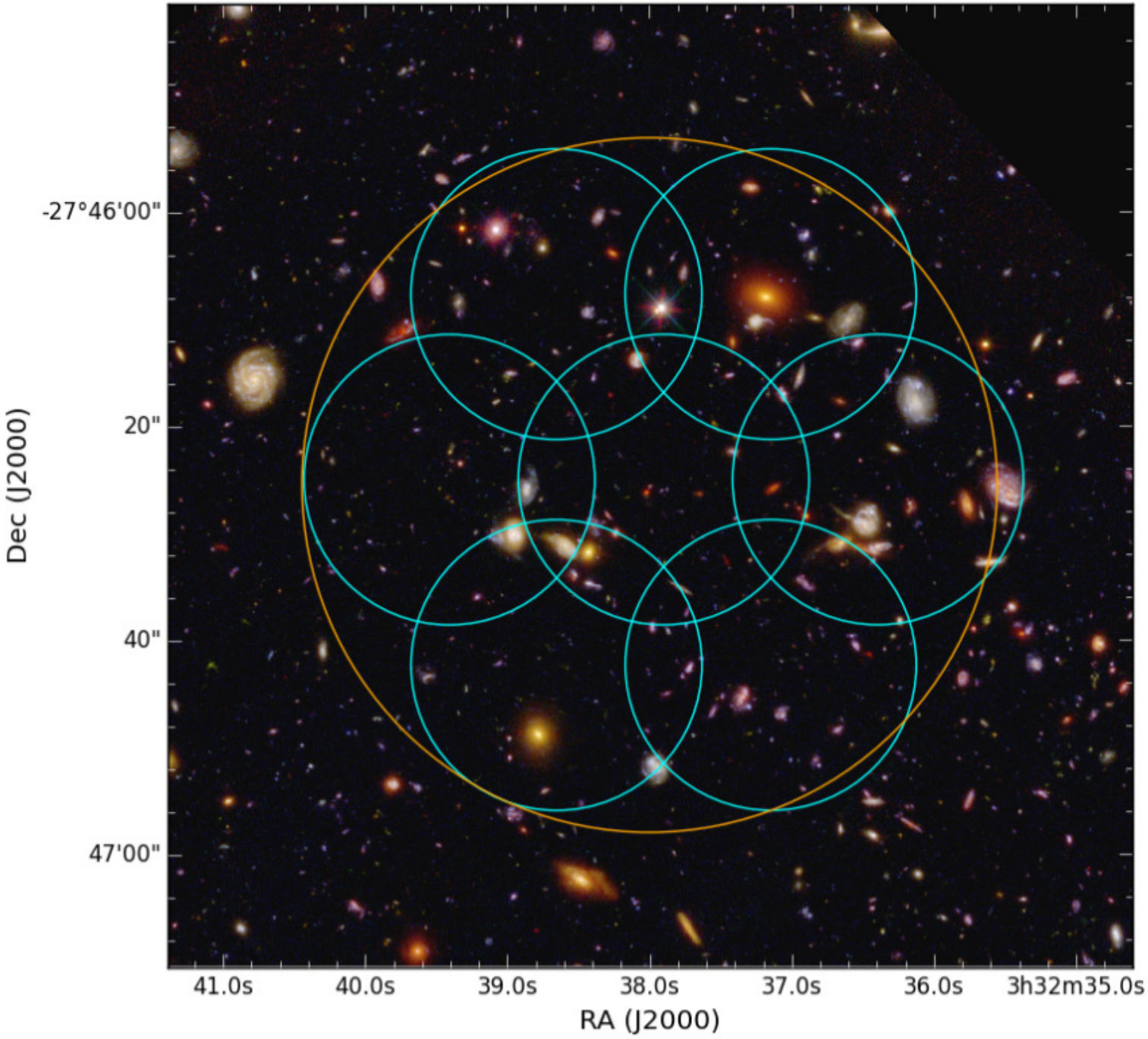
- ALMA bands

from Casey et al. (2014)

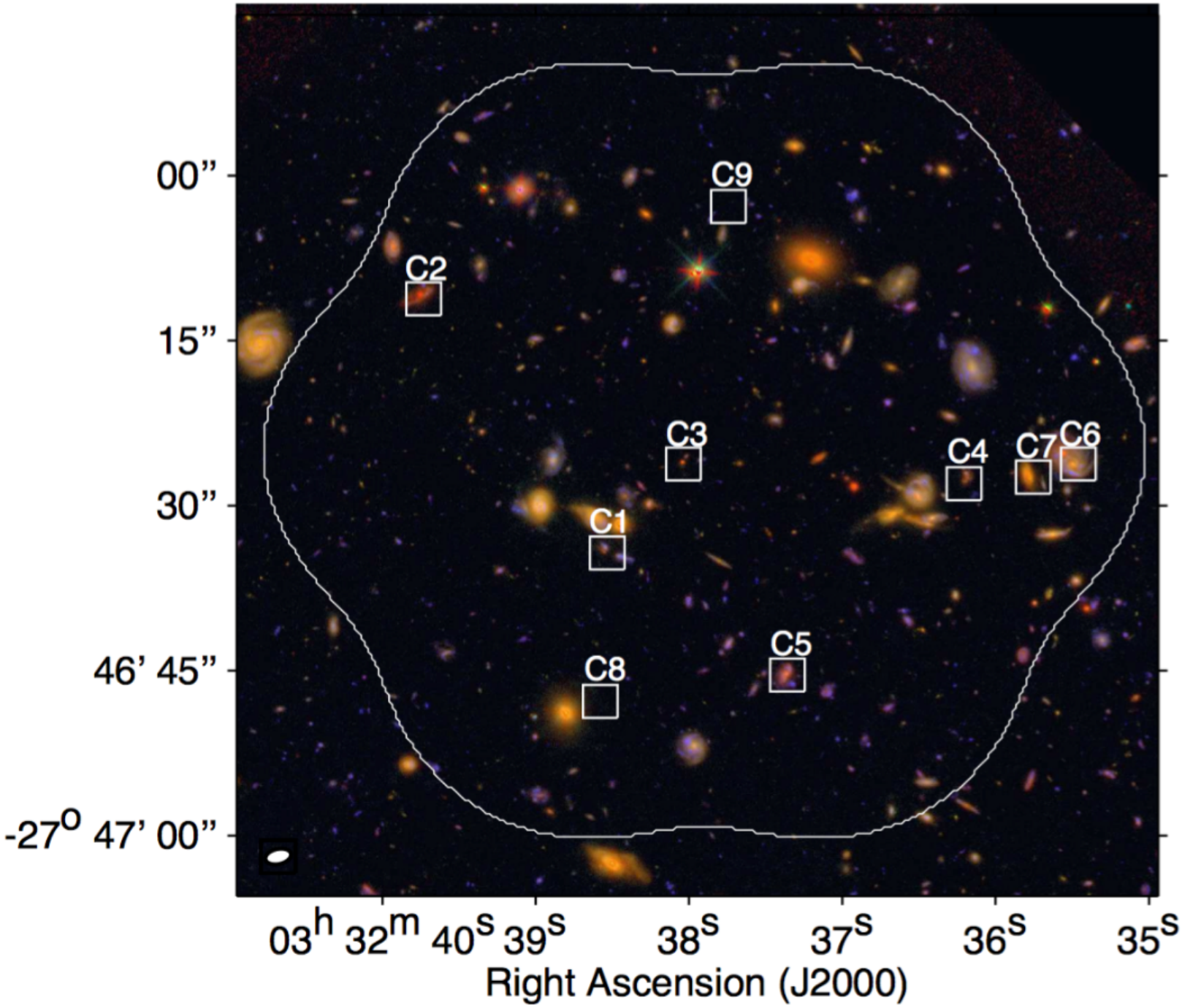
ALMA band 6 deep field (HUDF) (Dunlop et al. 2016)



ASPECS (Walter et al. 2016)

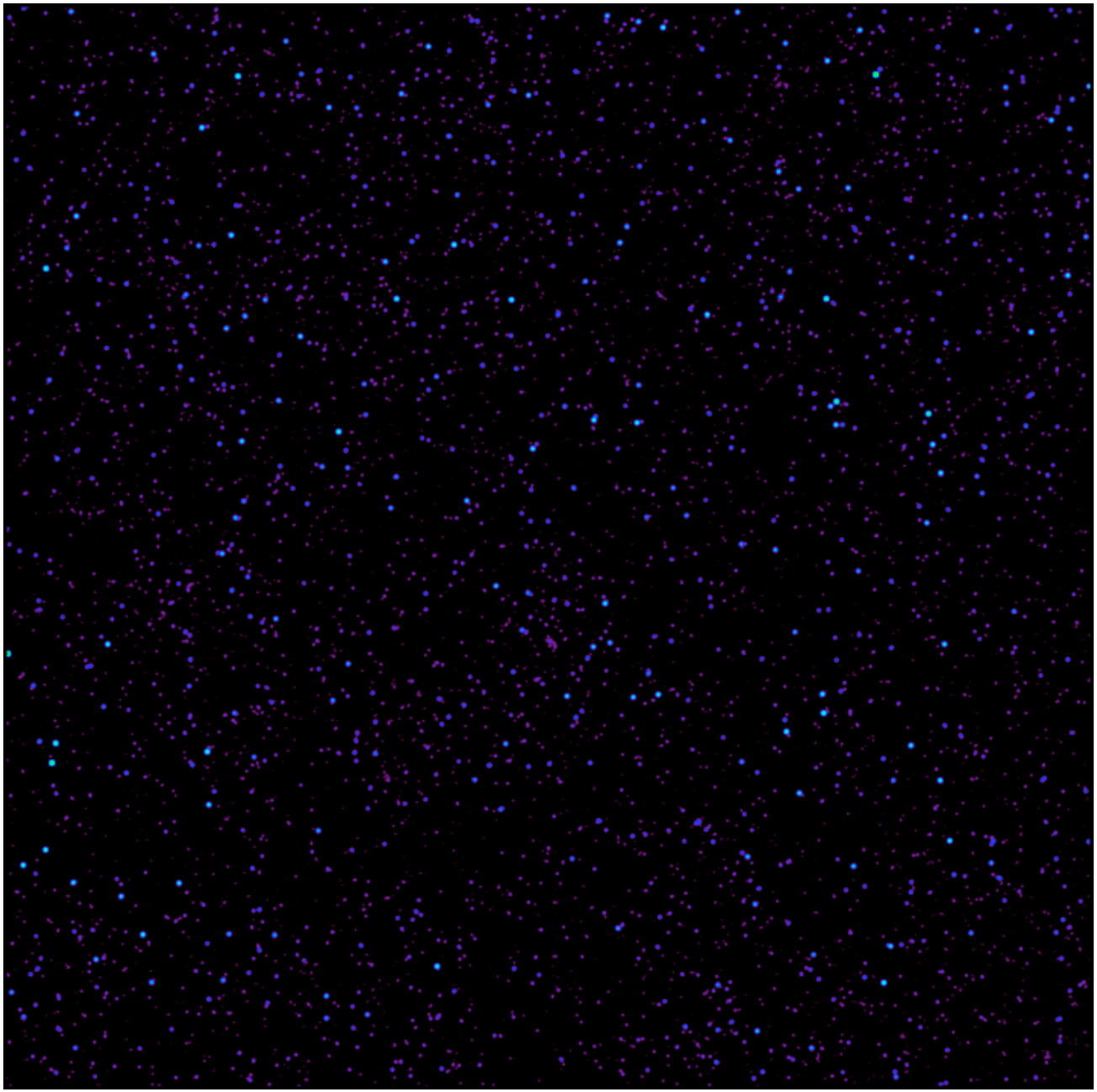


ASPECS: ALMA detections



z < 3

ALMA band 4 lightcone ('deep field')



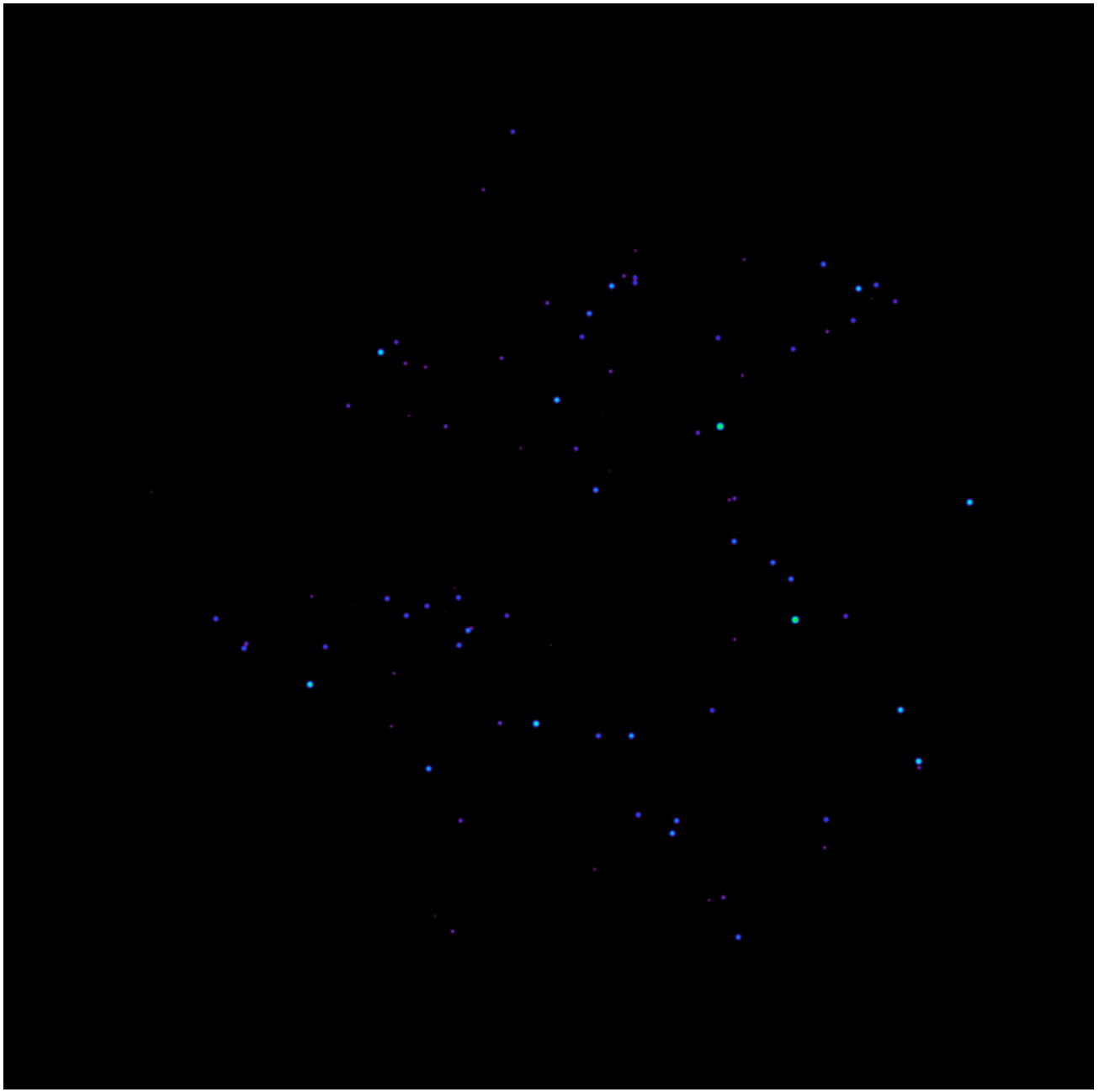
ALMA band 4 (~2 mm), compact configuration: ~3" resolution (~25 kpc at z=1.6)

Field size: 15' x 15'

Dust continuum

No noise!

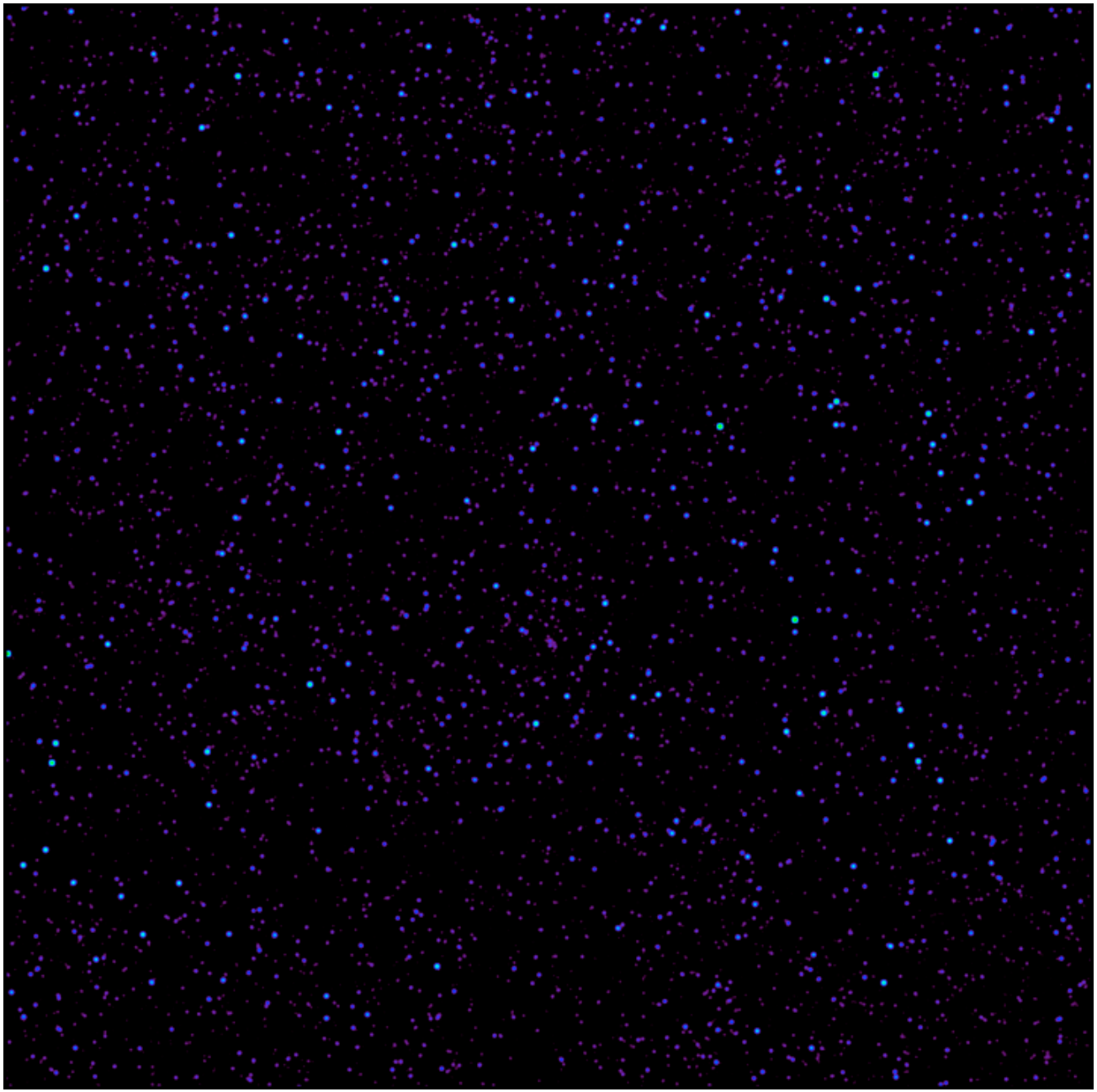
z=1.6 (proto-)cluster in a box



ALMA band 4 (~2 mm), compact configuration: ~3" resolution (~25 kpc at z=1.6)

Field size: 15' x 15' (~7x7 Mpc^2 at z-1.6)

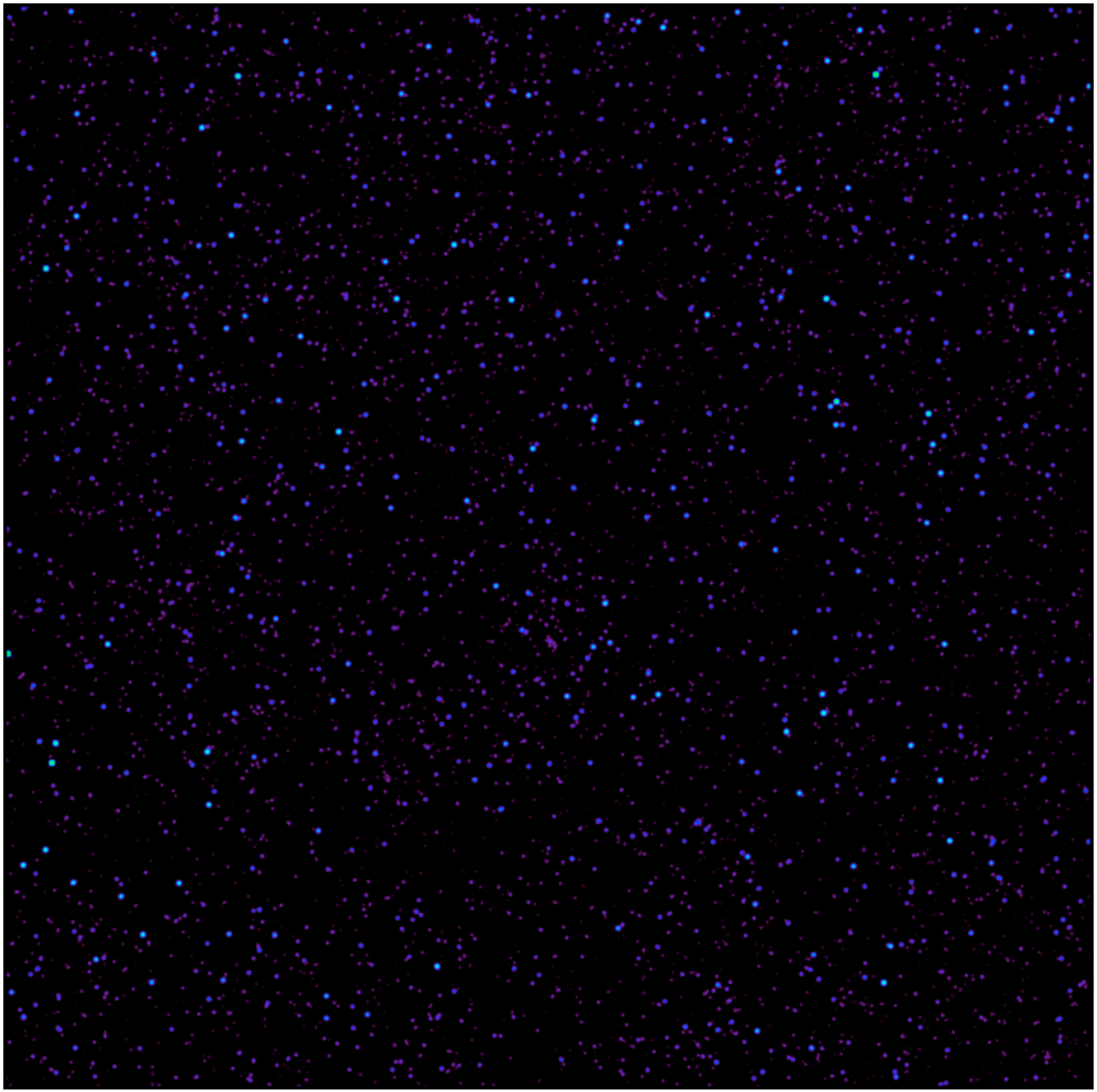
Add z=1.6 (proto-)cluster to lightcone



ALMA band 4 (~2 mm), compact configuration: ~3" resolution (~25 kpc at z=1.6)

Field size: 15' x 15'

without z=1.6 (proto-)cluster



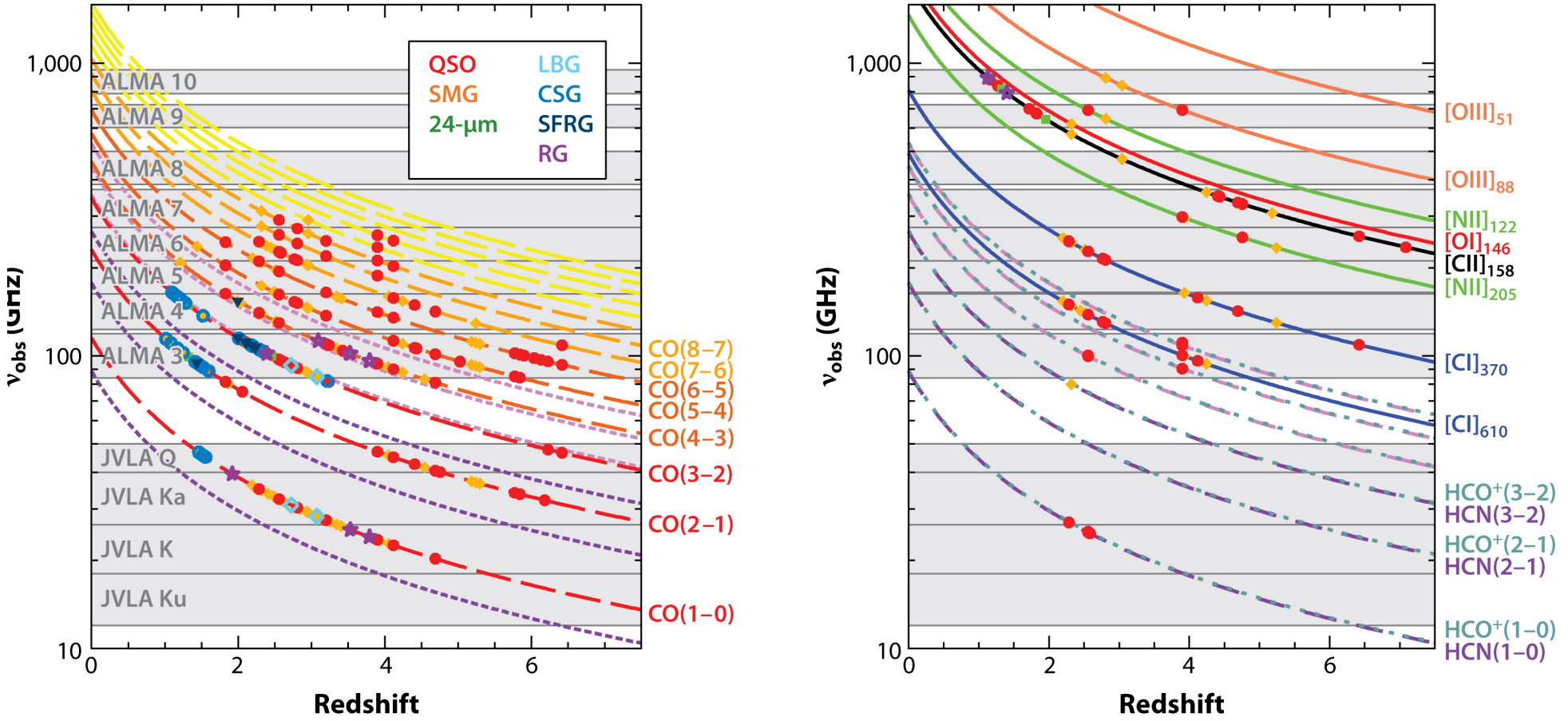
ALMA band 4 (~2 mm),
compact configuration:
~3” resolution
(~25 kpc at z=1.6)

Field size: 15’ x 15’

Dust continuum

No noise!

Molecules and atoms with ALMA and the JVLA



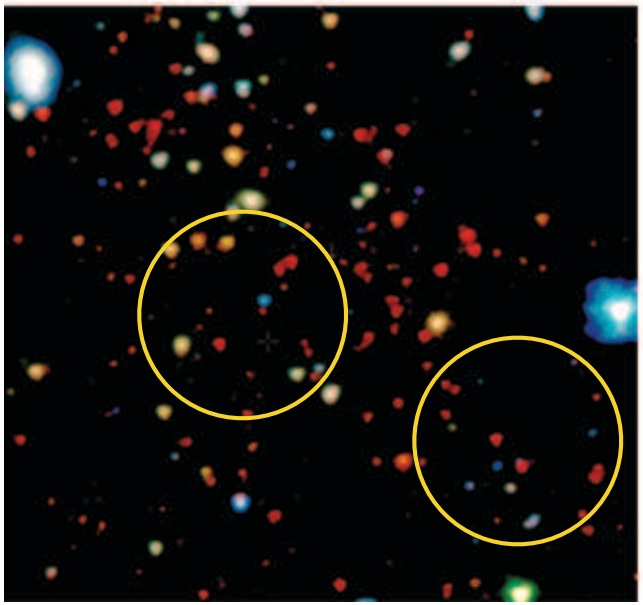
Molecular and atomic lines observable with ALMA (Carilli & Walter 2013)
Filled circles correspond to detections (up to 2013)

CO line emissions for galaxies in SpARCS clusters at z~1.6

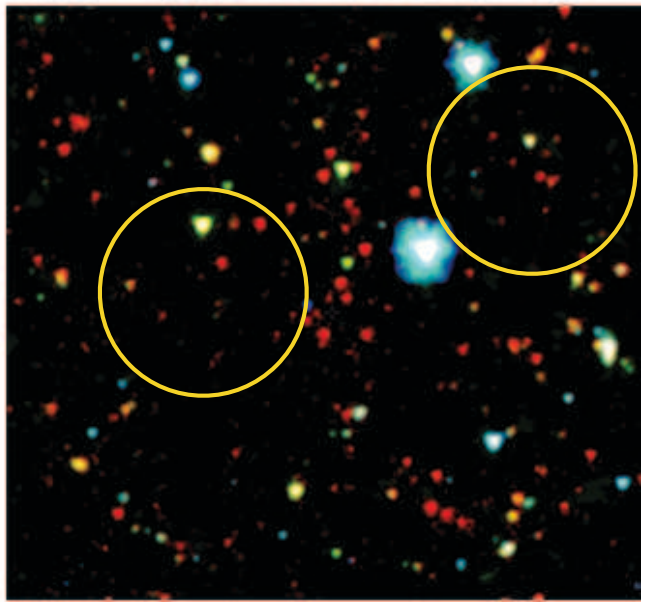
Fully observed ALMA Cycle 3 'filler' project (PI: Allison Noble, MIT)

- two pointings at 3 mm for three z~1.6 galaxy clusters from SpARCS (PI: Gillian Wilson, UC Riverside)
- **CO(2-1)** line emission of sources with confirmed spectroscopic redshifts
- additional data in 18 bands from UV to 500 micron (*Herschel* SPIRE)

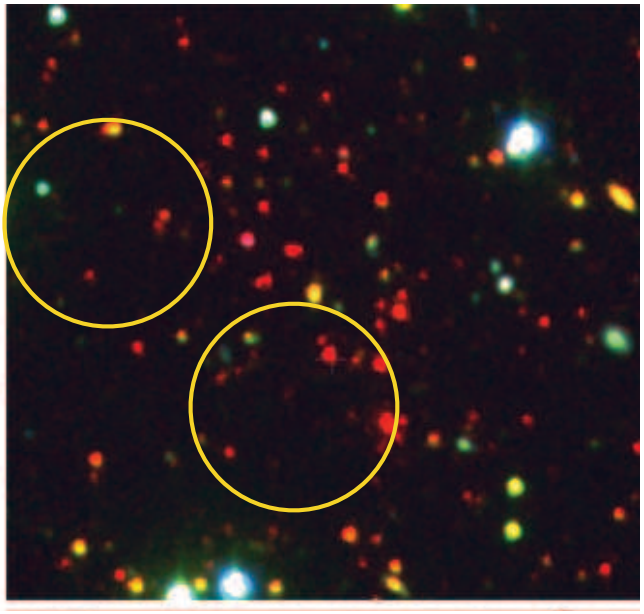
g′z′[3.6] images of our target clusters from the SpARCS catalogue and their band 3 pointings (yellow circles):



J0224



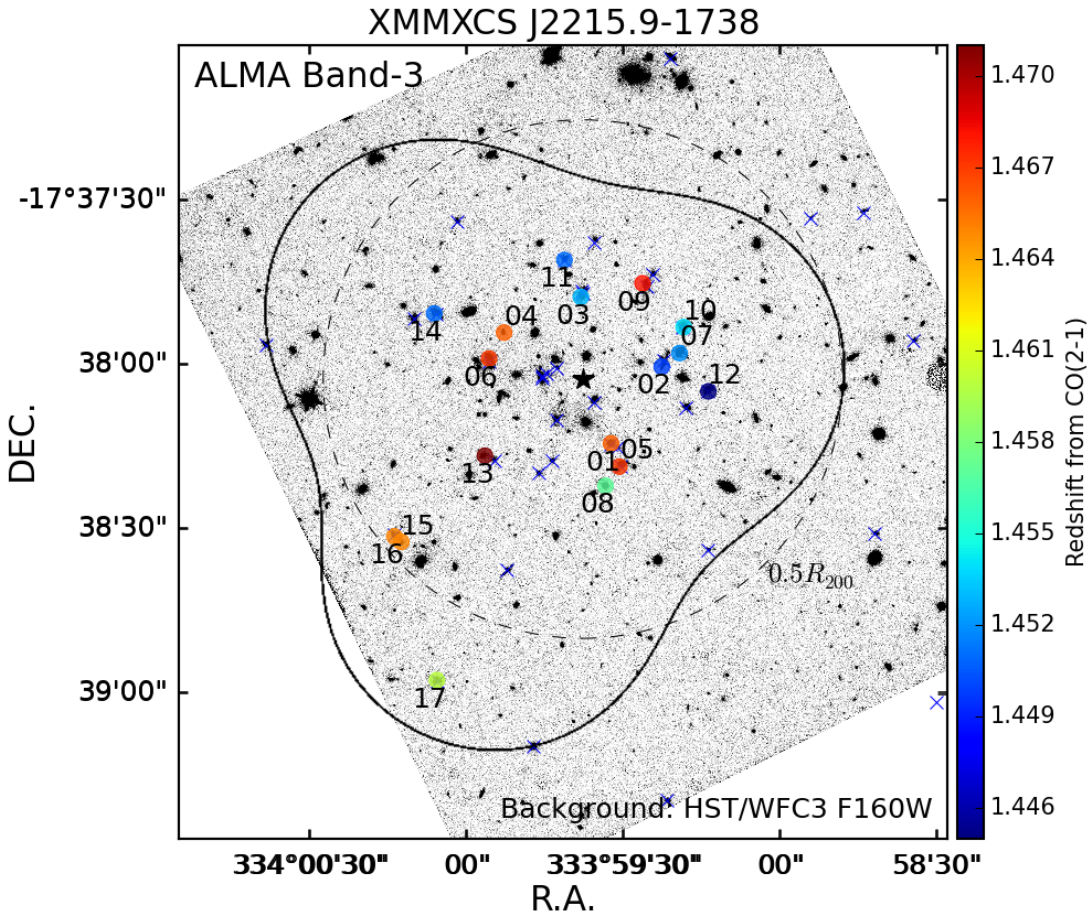
J0225



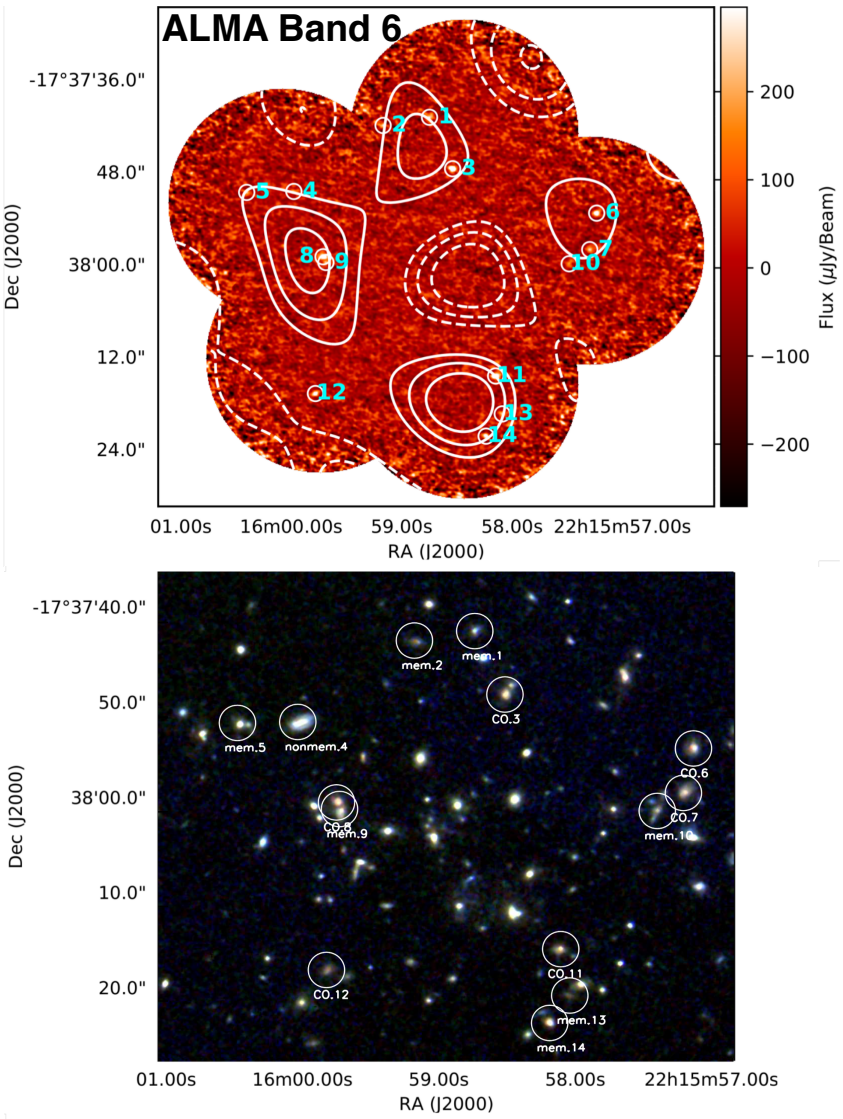
J0330

CO line emissions for galaxies in XCS J2215 at z~1.6

Hayashi et al. (2017)

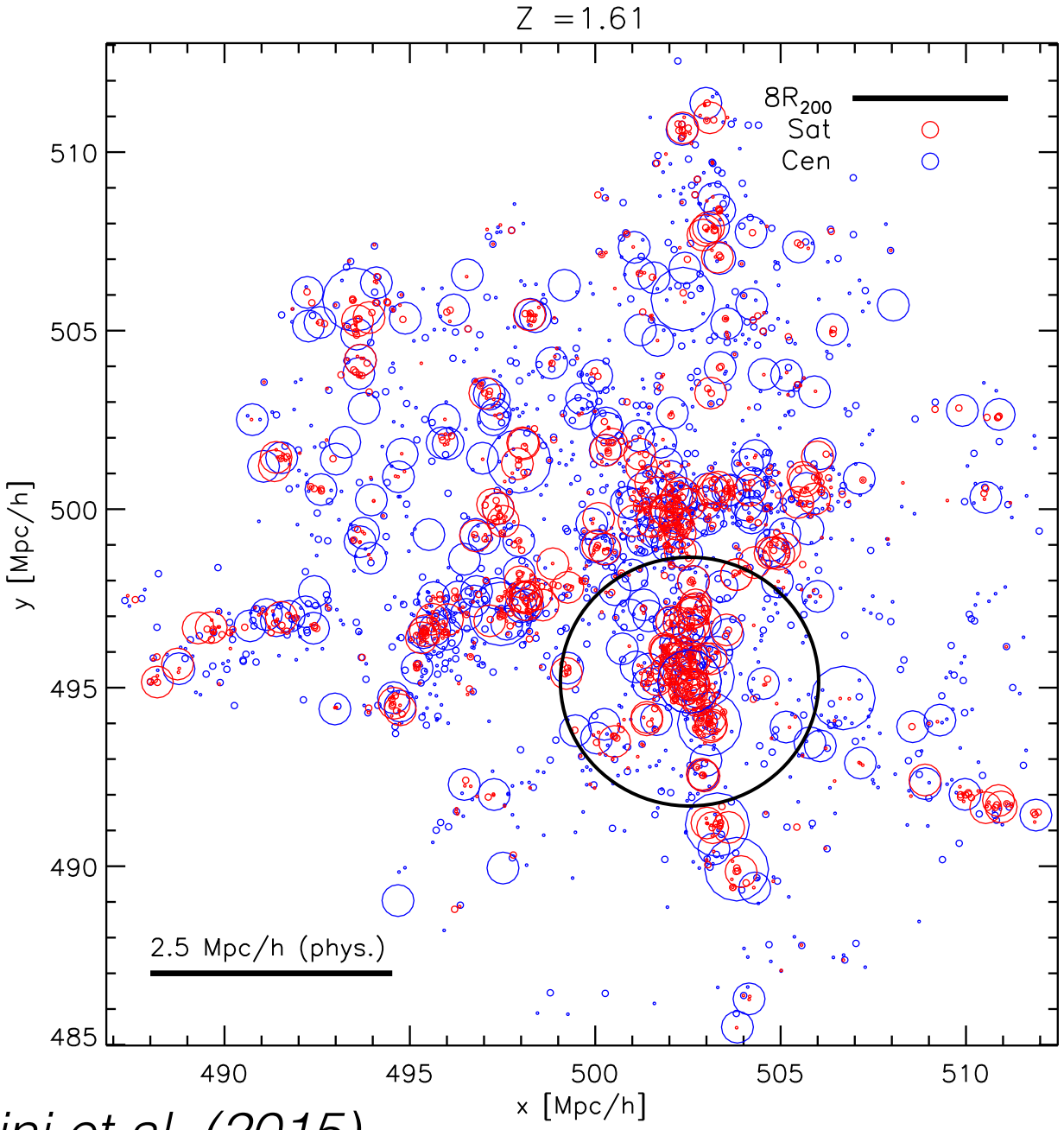


Stach et al. (2017)



Galaxies in the core region

Mapping a ‘whole’ proto-cluster with ALMA ?



band 3 beam

band 6 beam

~15’

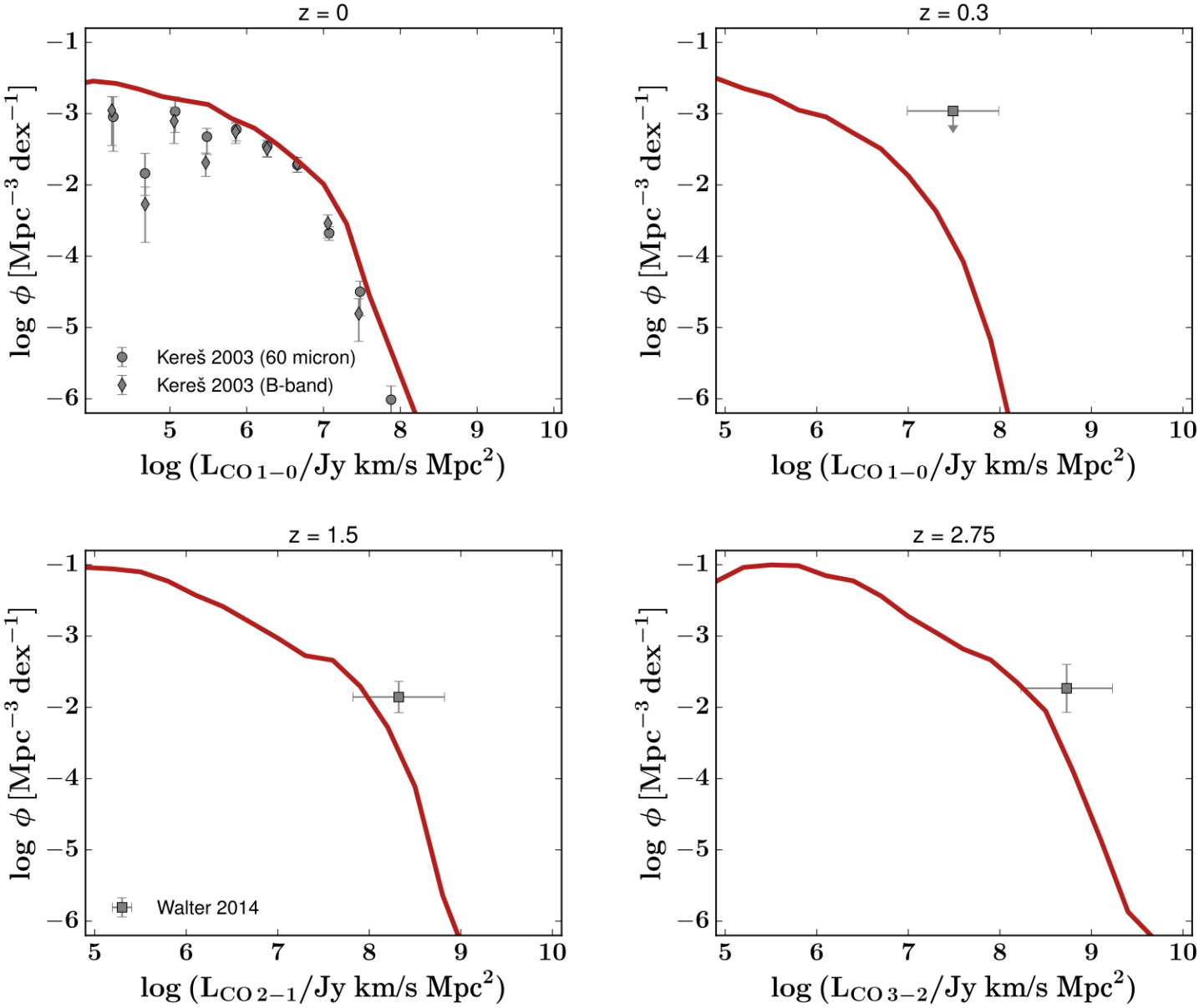
15’x15’ is
~1000 band 3 beams
~6000 band 6 beams

Contini et al. (2015)

Semi-analytical galaxy formation model with radiative transfer code

Predicted CO Luminosity Functions

(Popping, van Kampen, et al. 2016)



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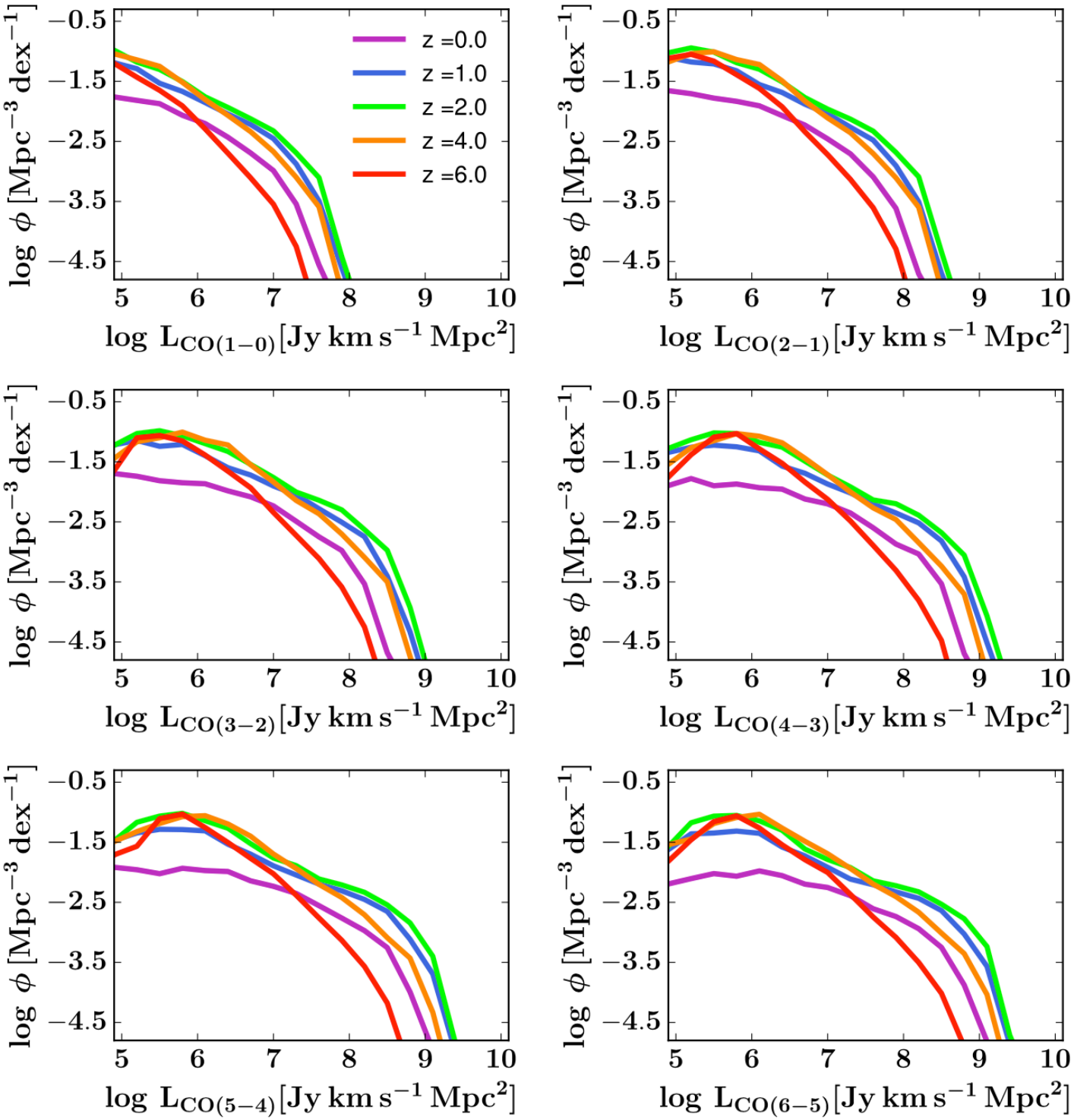


Survey speeds for CO transitions at several redshifts

(Popping, van Kampen, et al. 2016)

HUDF: ~4.5 arcmin^2

Bandwidth for sensitivity: 300 km/s

To get down to L$_*$

Transition	Redshift	Observed frequency (GHz)	Instrument	rms/pointing (mJy)	Survey speed (h/arcmin^2)
CO J = 1–0	0	115.22	ALMA band 3	5×10^5	0.03
CO J = 1–0	1	67.64	ALMA band 2	0.042	44.24
CO J = 1–0	2	38.42	ALMA band 1	0.013	20.51
CO J =1–0	2	38.42	JVLA Ka	0.013	90.00
CO J =1–0	2	38.42	ngVLA Ka	0.013	18.00
CO J =1–0	4	23.05	JVLA K	0.0036	239.18
CO J =1–0	4	23.05	ngVLA K	0.0036	47.83
CO J =1–0	6	16.47	JVLA Ku	0.0014	341.96
CO J =1–0	6	16.47	ngVLA Ku	0.0014	68.39
CO J =2–1	0	230.54	ALMA band 6	2×10^6	0.12
CO J =2–1	1	115.26	ALMA band 3	0.165	4.9
CO J =2–1	2	76.85	ALMA band 2	0.053	6.22
CO J =2–1	4	46.11	JVLA Q	0.0153	132.84
CO J =2–1	4	46.11	ngVLA Q	0.0153	26.57
CO J =2–1	6	32.93	ALMA band 1	0.0044	130.54
CO J =2–1	6	32.93	JVLA Ka	0.0044	223.5
CO J =2–1	6	32.93	ngVLA Ka	0.0044	44.70

Transition	Redshift	Observed frequency (GHz)	Instrument	rms/pointing (mJy)	Survey speed (h/arcmin^2)
CO J =3–2	0	345.8	ALMA band 7	4×10^6	0.27
CO J =3–2	1	172.9	ALMA band 5	0.201	0.73
CO J =3–2	2	115.26	ALMA band 3	0.146	6.16
CO J =3–2	4	69.16	ALMA band 2	0.036	28.75
CO J =3–2	6	49.4	JVLA Q	0.0095	3345.33
CO J =3–2	6	49.4	ngVLA Q	0.0095	669.01
CO J =4–3	0	461.04	ALMA band 8	7×10^6	0.49
CO J =4–3	1	230.52	ALMA band 6	0.750	0.21
CO J =4–3	2	153.68	ALMA band 4	0.278	0.74
CO J =4–3	4	92.21	ALMA band 3	0.099	2.95
CO J =4–3	6	65.86	n/a	0.018	n/a
CO J =5–4	0	576.27	n/a	10^7	n/a
CO J =5–4	1	288.13	ALMA band 7	1.50	0.19
CO J =5–4	2	192.09	ALMA band 5	0.35	1.16
CO J =5–4	4	115.25	ALMA band 3	0.106	11.66
CO J =5–4	6	82.32	ALMA band 2	0.0212	36.73
CO J =6–5	0	691.47	ALMA band 9	10^7	1.09
CO J =6–5	1	345.74	ALMA band 7	1.304	0.27
CO J =6–5	2	230.49	ALMA band 6	0.375	0.85
CO J =6–5	4	138.29	ALMA band 4	0.137	2.91
CO J =6–5	6	98.78	ALMA band 3	0.0026	49.88

Survey speed @ z=1.6

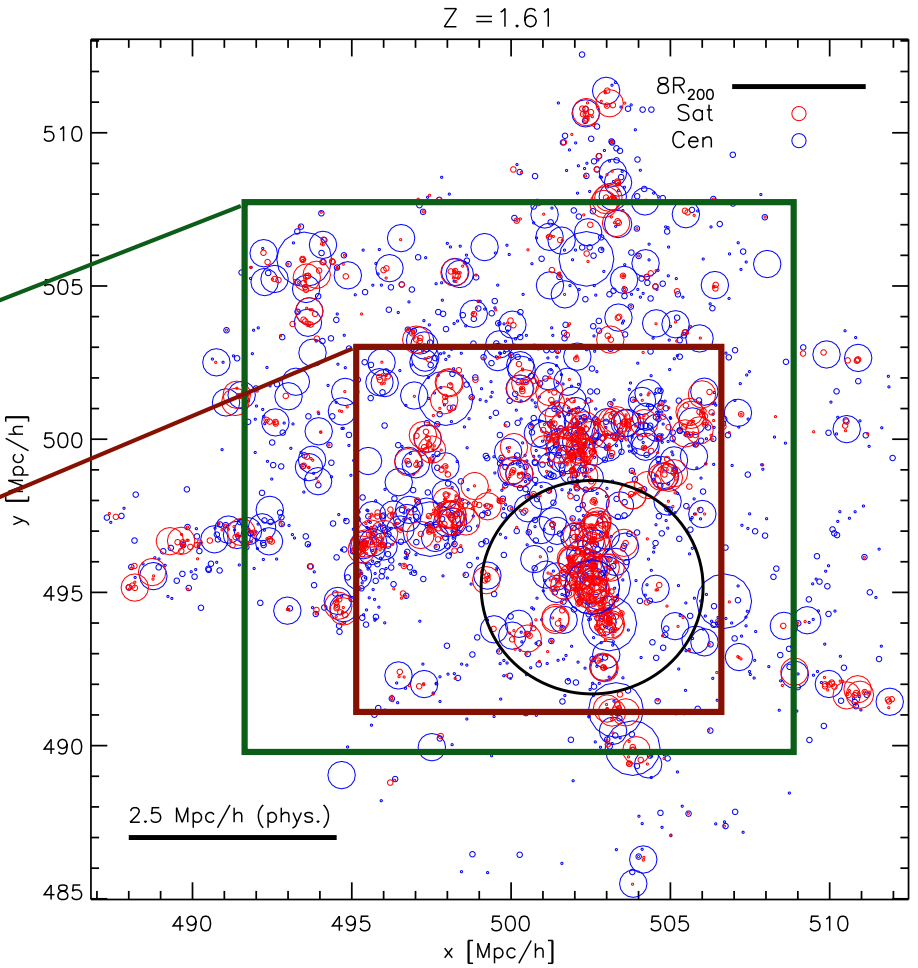
line	obs. freq. [GHz]	band	mapping speed [h / sq. arcmin]	beams / sq. arcmin
CO(2-1)	88.7	3	4.4	4.2
CO(3-2)	133.0	4	1.7	9.4
CO(4-3)	177.3	5	0.86	16.8
CO(5-4)	221.6	6	0.35	26.3
CO(6-5)	265.9	6	0.59	37.7

Bandwidth for sensitivity: 300 km/s
Band 5 note: atmostpheric water line at 183 GHz

→ CO(5-4) band 6:

15'x15': 79h
(~6000 pointings)

10'x10': 35h
(~2500 pointings)



- ~50s on-source time per pointing
- of order 5x longer @ z=4