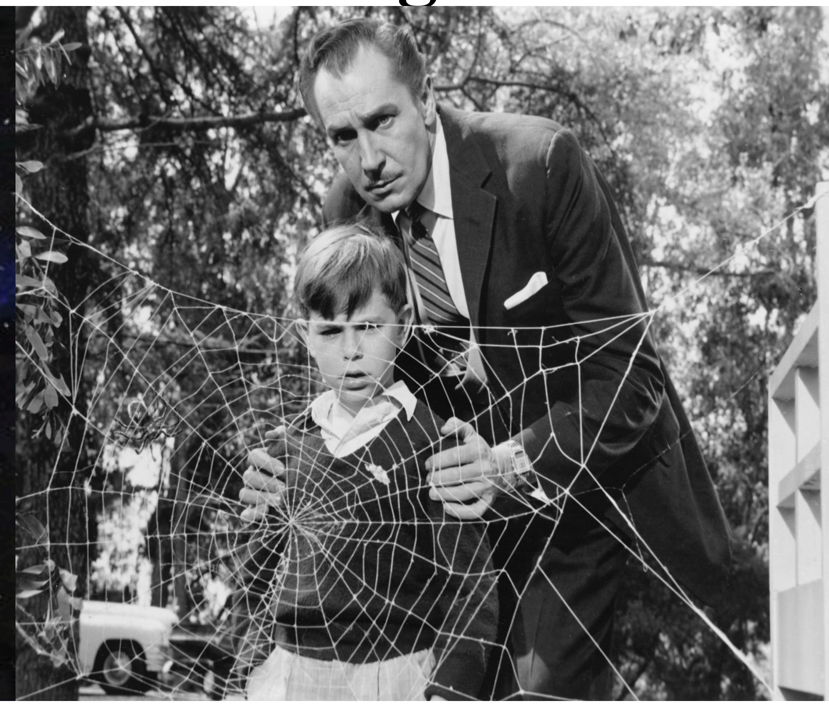
GOBIERNO DE ESPAÑA
MINISTERIO DE ECONOMÍA Y COMPETITIVIDAD

ULL Universidad de La Laguna

Impact of environment on molecular gas reservoirs probed in distant cluster and field galaxies



Helmut Dannerbauer

Instituto de Astrofísicas de Canarias

Motivation

•lack of such studies on (proto)cluster galaxies
➔see also talks by Kodama, Noble

•measure the fuel of star formation ➔molecular gas reservoirs via CO(1-0)

•formation of red sequence galaxies (in clusters)

•characterize star-formation process

•how obscured are protoclusters?

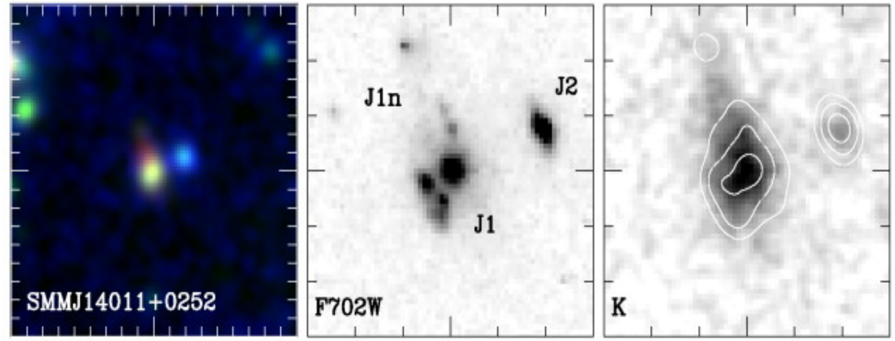
•impact of environment on molecular gas reservoirs

Dusty Star-Forming Galaxies

see also talks by TC, Cortzen, Gulberg

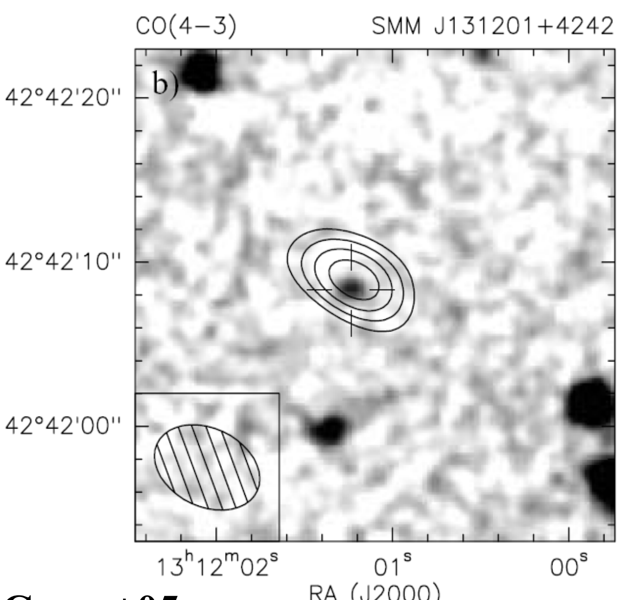
- very massive up to $10^{11} M_{\odot}$
- gas-rich
- high SFR: several 100 $M_{\odot}$/yr
- merger-like morphology
- ellipticals in formation
- $\langle z \rangle = 2.5$

➔ ***excellent tracers of mass-density peaks***

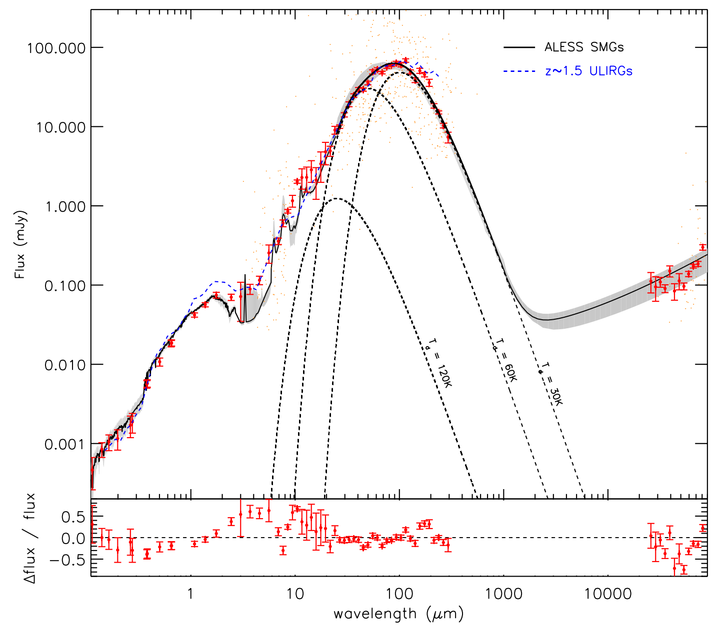


Ivison+00

see also review by Casey+2014



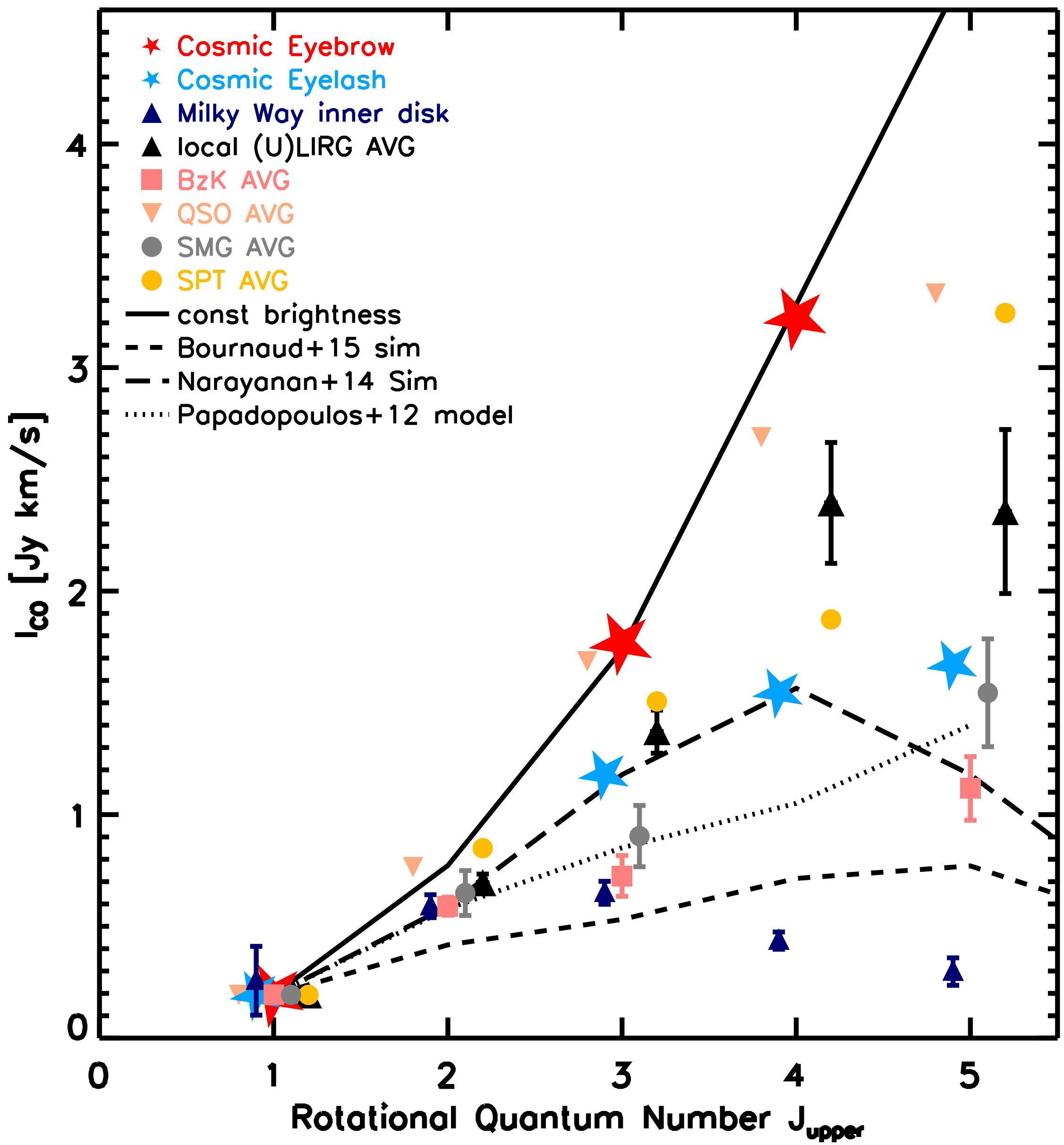
Greve+05



Swinbank+14

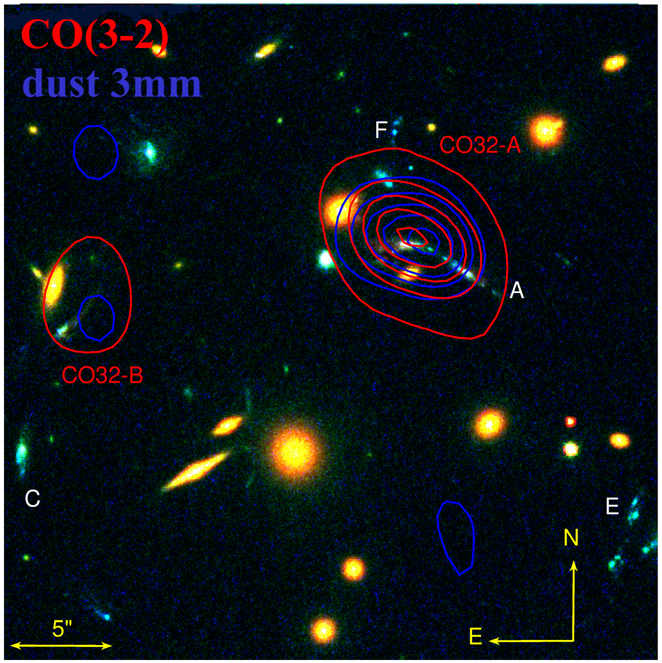
CO Spectral Line Energy Distribution

see also talk by Klitsch

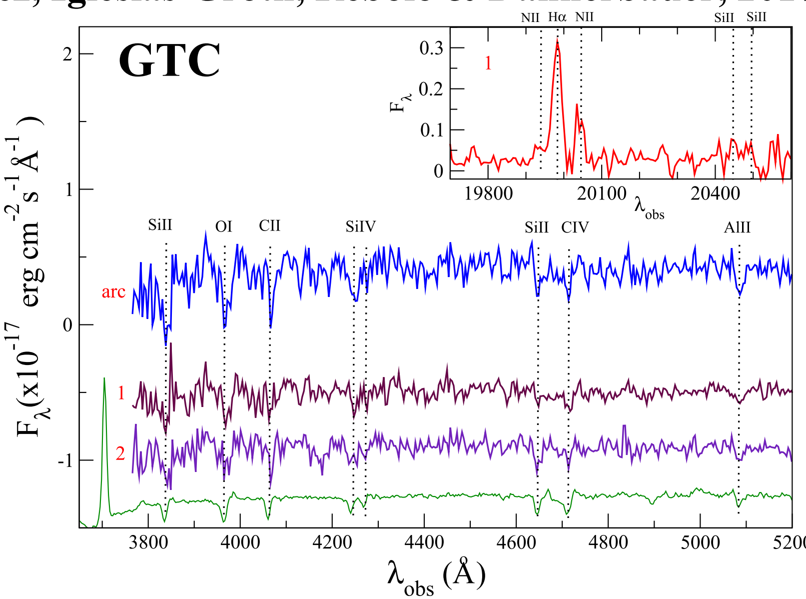


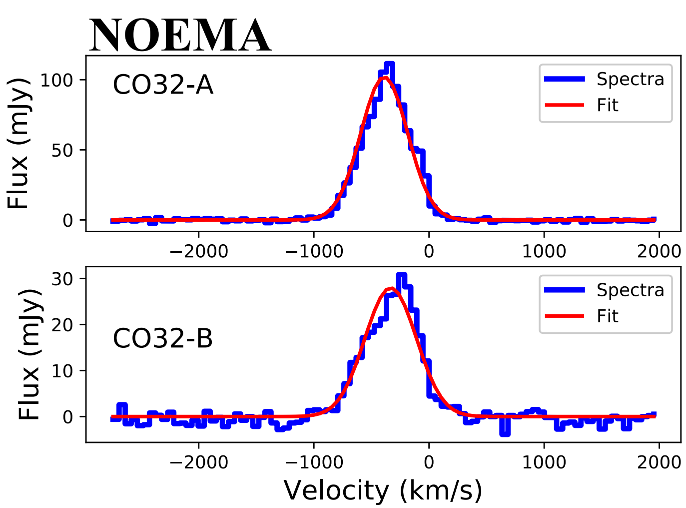
Dannerbauer et al. 2019, AJ, in press (astro-ph/1812.03845)

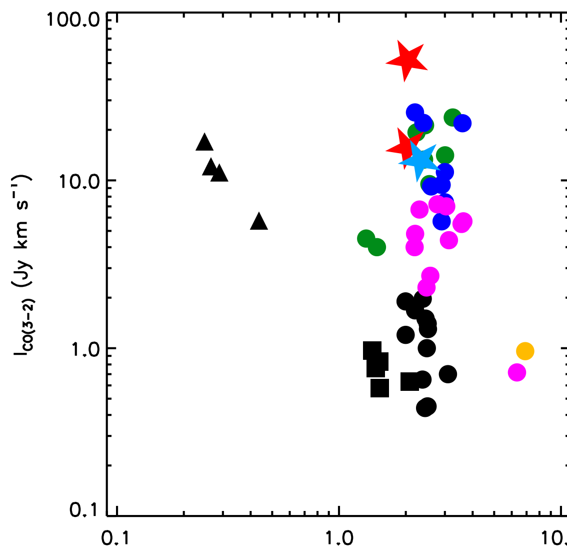
Cosmic Eyebrow: ultra-bright lensed SMG at z=2.04

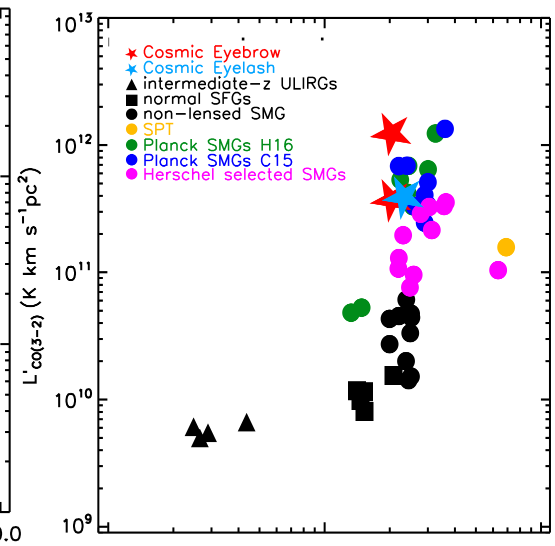


Diaz-Sanchez, Iglesias-Groth, Rebolo & Dannerbauer, 2017, ApJL







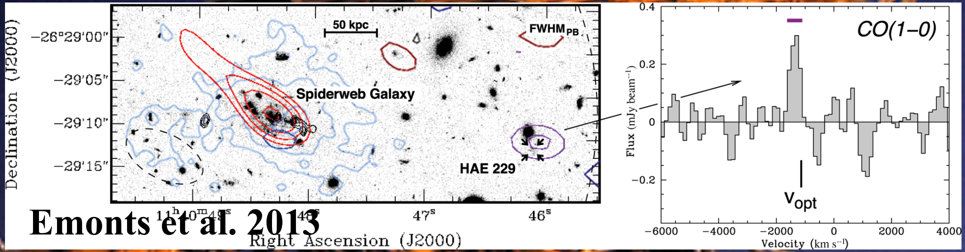


Dannerbauer, Harrington, Diaz-Sanchez, IglesiasGroth, Rebolo, et al., 2019, AJ, in press

Why ATCA

•currently only with ATCA it is possible to detect CO(1-0) of galaxies at z=2 in the southern sky – band 1 @ ALMA

•especially work by B. Emonts on HzRGs showed that this kind of work should be feasible



Emonts et al. 2013

•CO(1-0) transition is indispensable to measure the total cold molecular gas reservoir, the fuel of star formation

•should be sensitive to low-surface brightness emission

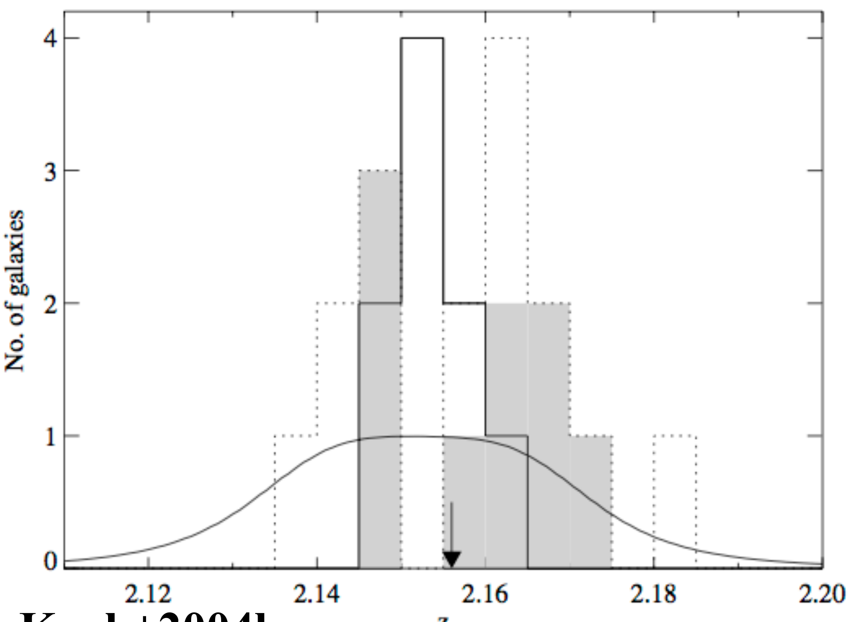
•combine with high-J CO transitions from ALMA

HzRG: MRC1138-262 alias Spiderweb Galaxy
→will evolve into a Brightest Cluster Galaxy

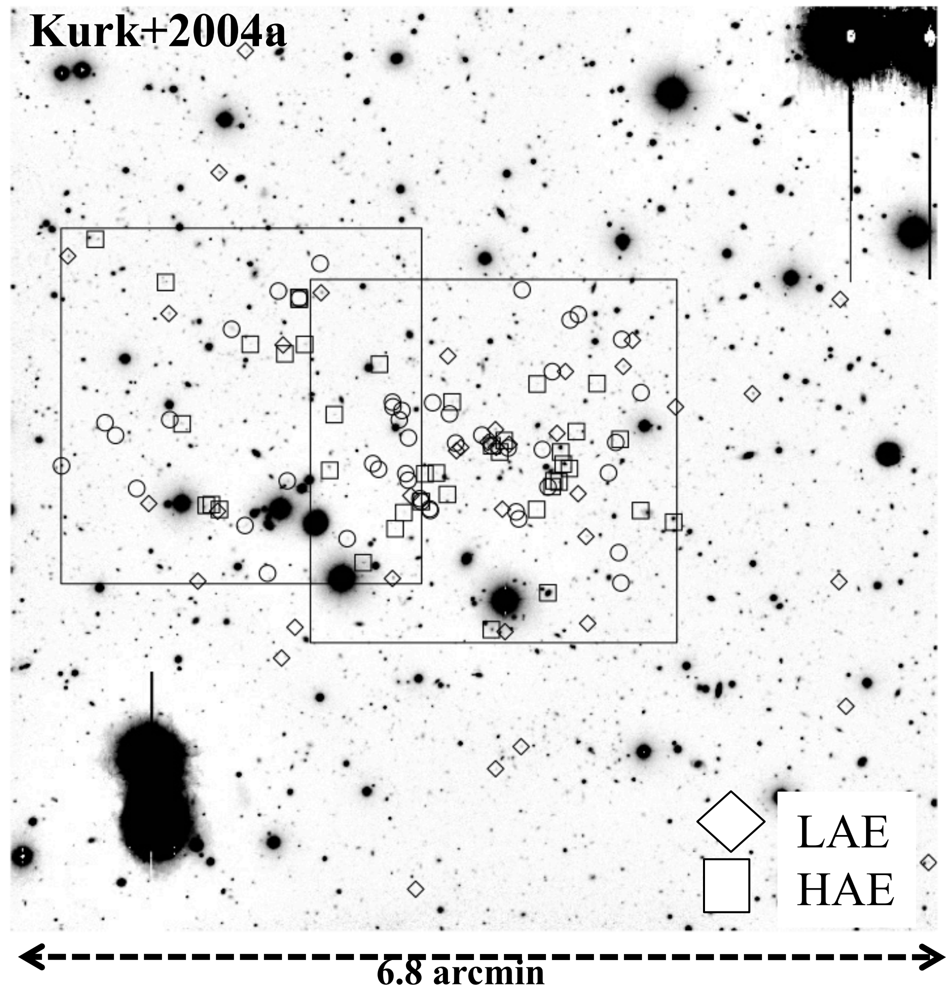
***z* = 2.16**
(23% of age Universe)

Miley et al. 2006 **(Credits: NASA, ESA, George Miley and Roderik Overzier (Leiden Observatory, NL)**

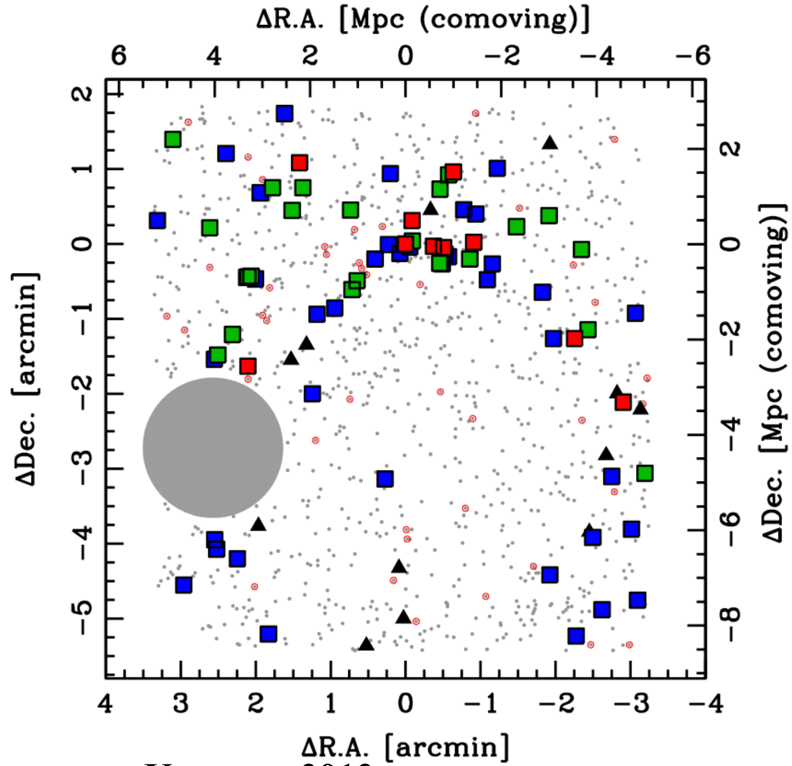
Protocluster MRC1138 @ z=2.16



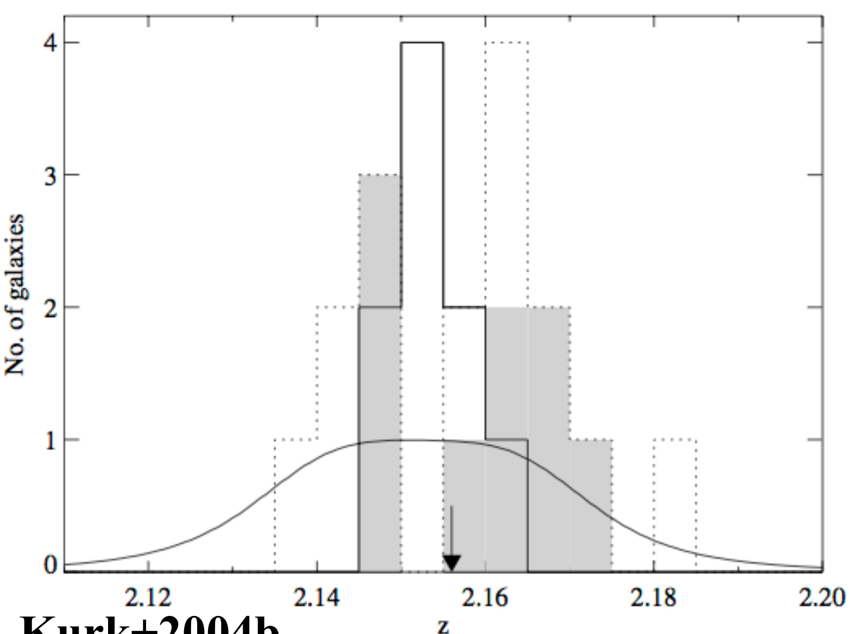
Kurk+2004b



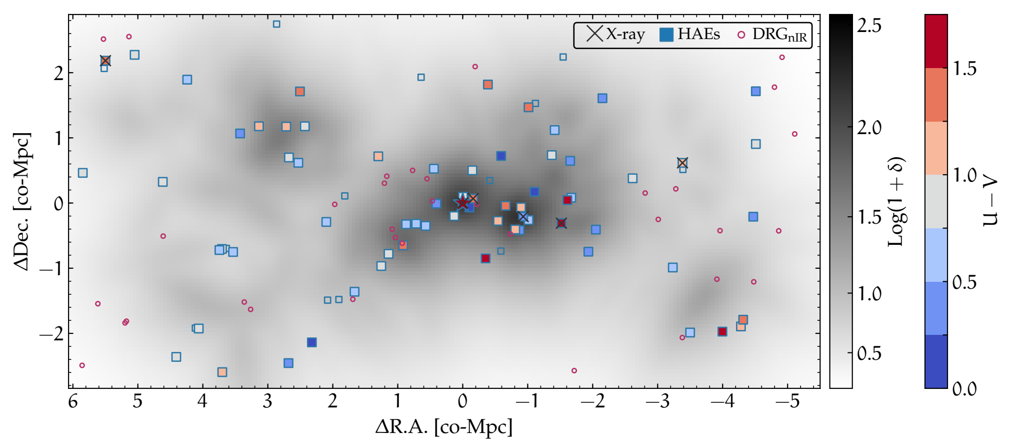
Protocluster MRC1138 @ z=2.16



Koyama+2013



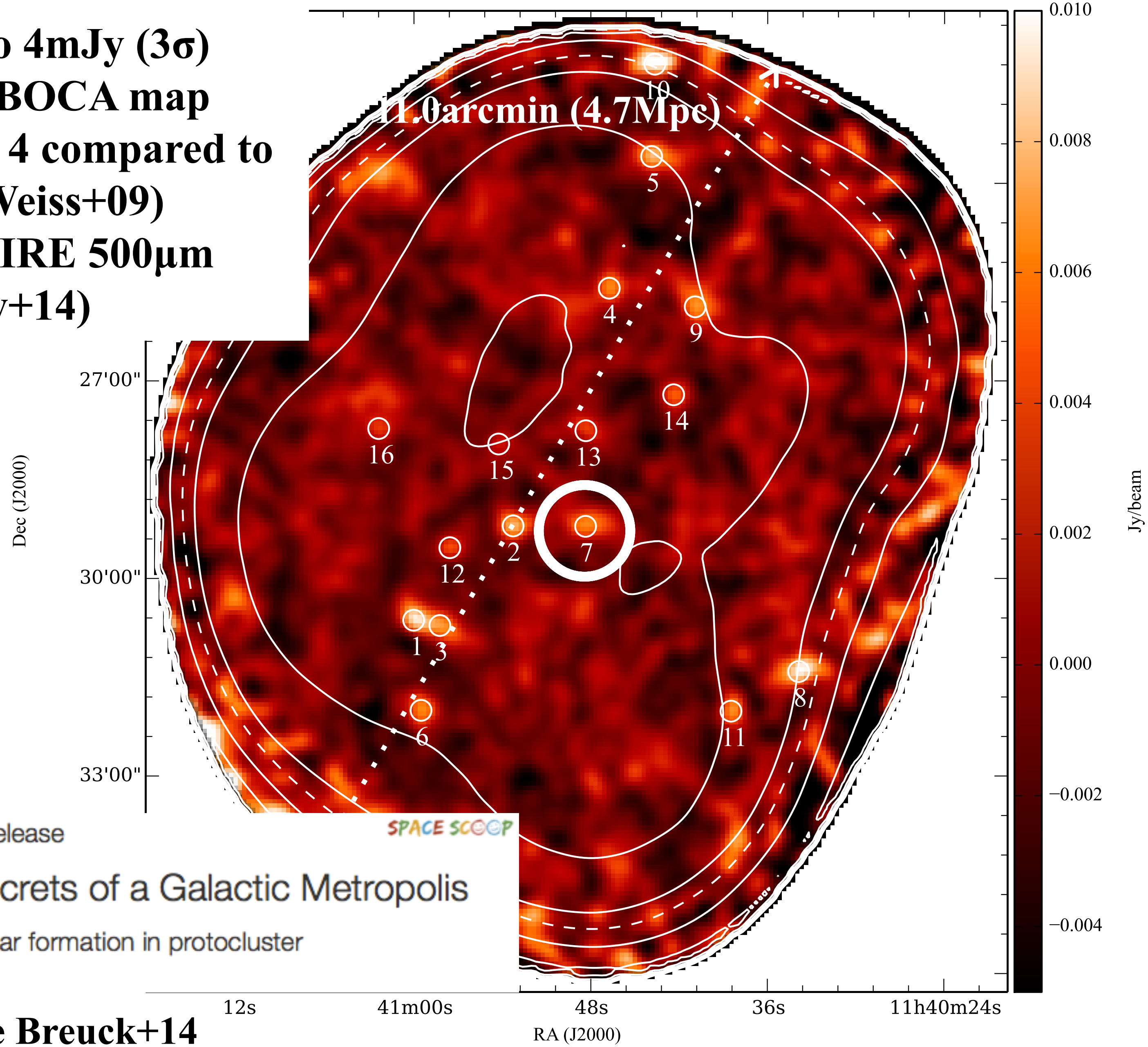
Kurk+2004b



Shimakawa … HD et al. 2018, MNRAS

APEX LABOCA Observations

- 16 sources down to 4mJy (3σ)
- one of deepest LABOCA map
- overdensity factor 4 compared to blank fields (e.g. Weiss+09)
- consistent with SPIRE 500µm overdensity (Rigby+14)



eso1431 — Science Release

SPACE SCOOP

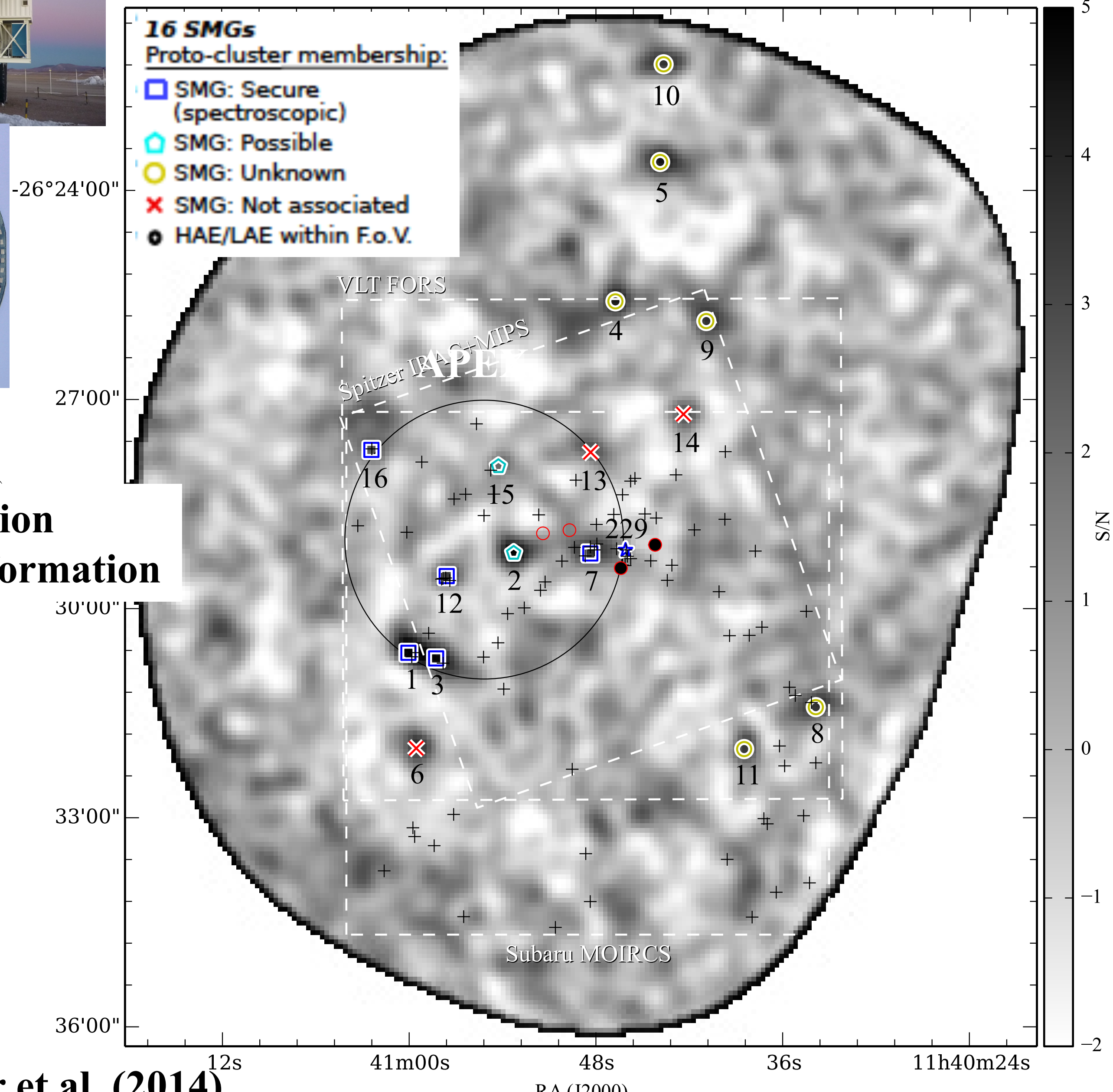
Construction Secrets of a Galactic Metropolis

APEX reveals hidden star formation in protocluster

15 October 2014

Dannerbauer, Kurk, De Breuck+14

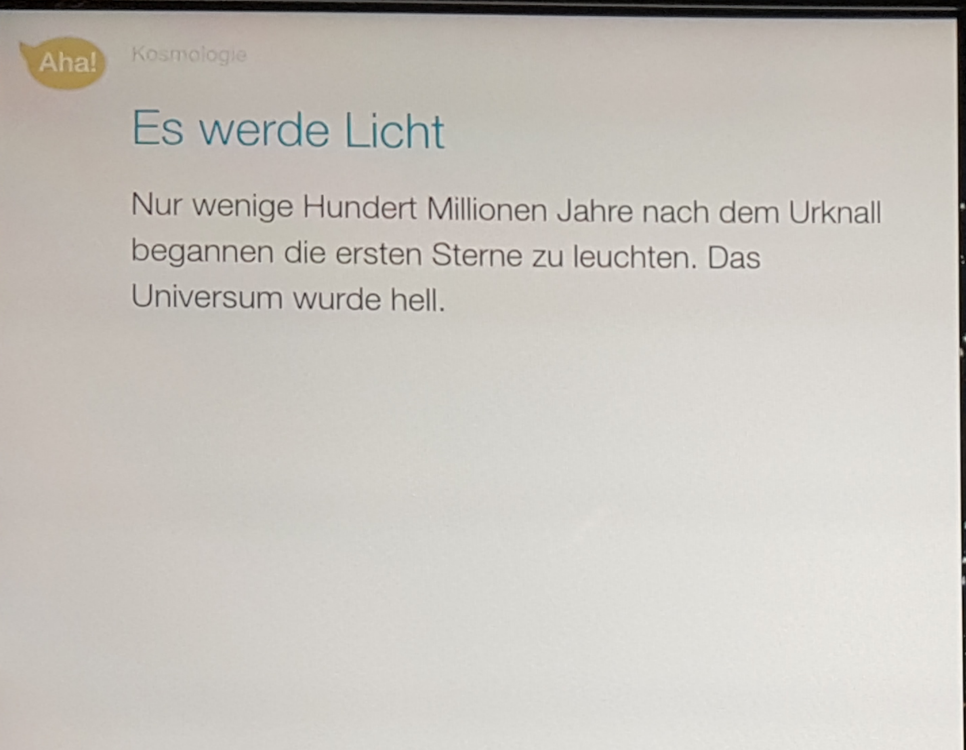
Proto-Cluster Membership



rather accretion than in-situ formation

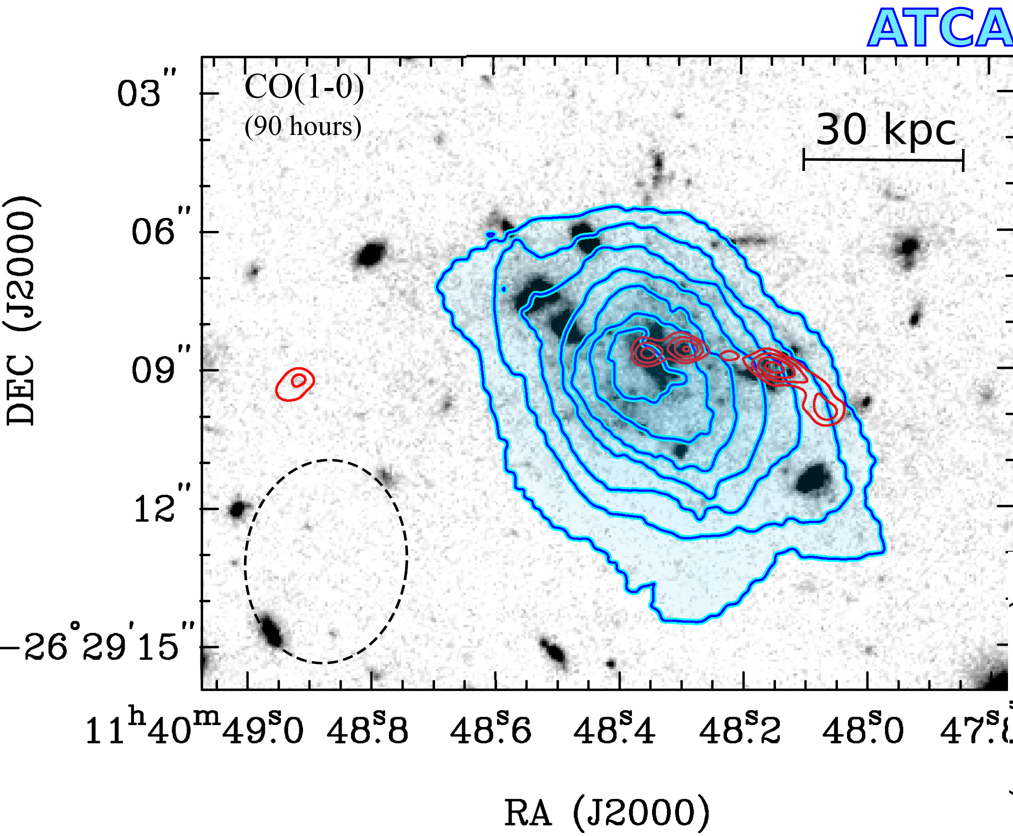
Dannerbauer et al. (2014)


ESO Supernova
Planetarium & Visitor Centre
Inspiring younger generations to appreciate and understand the Universe around us

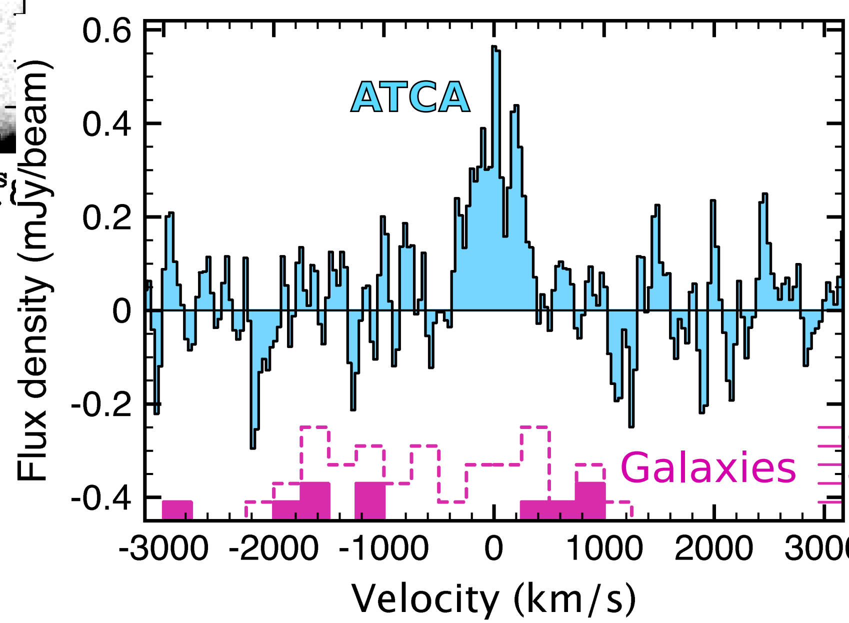

Aha!
Kosmologie
Es werde Licht
Nur wenige Hundert Millionen Jahre nach dem Urknall begannen die ersten Sterne zu leuchten. Das Universum wurde hell.


Künstlerische Darstellung des ersten Galaxienhaufens.
Credit: ESO/M. Kornmesser

Spiderweb Galaxy: Cold Molecular IGM

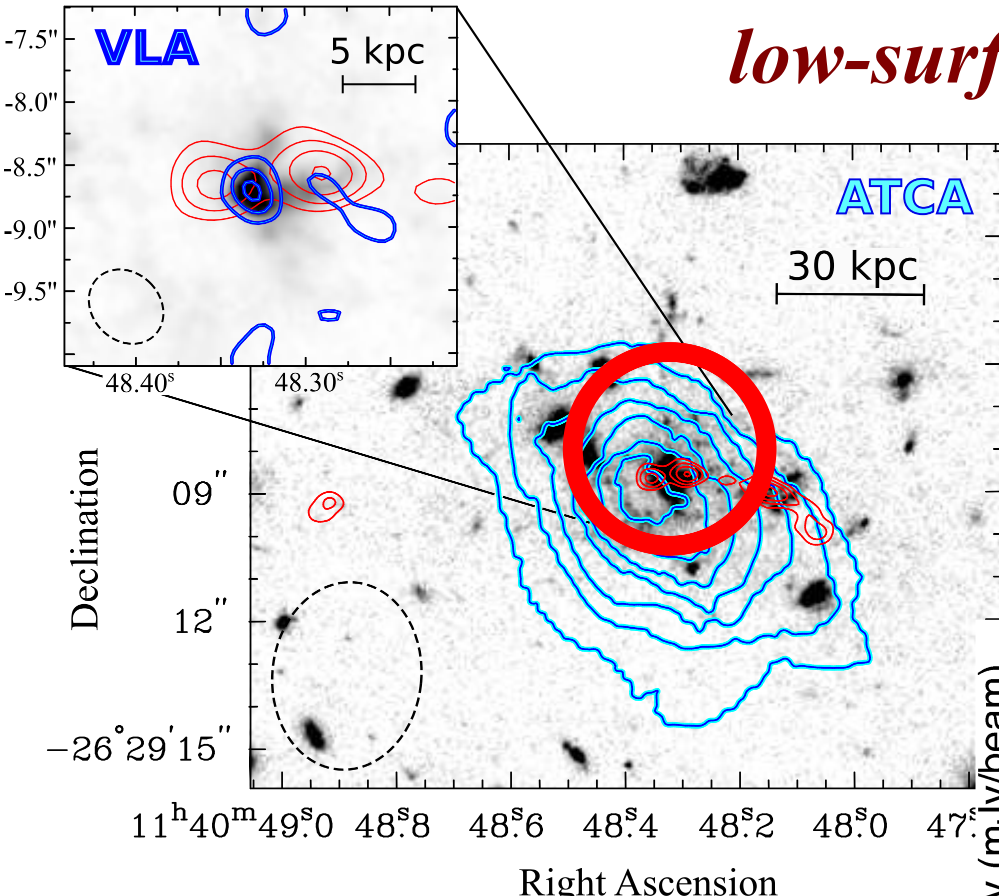


Emonts … HD et al. 2016, Science



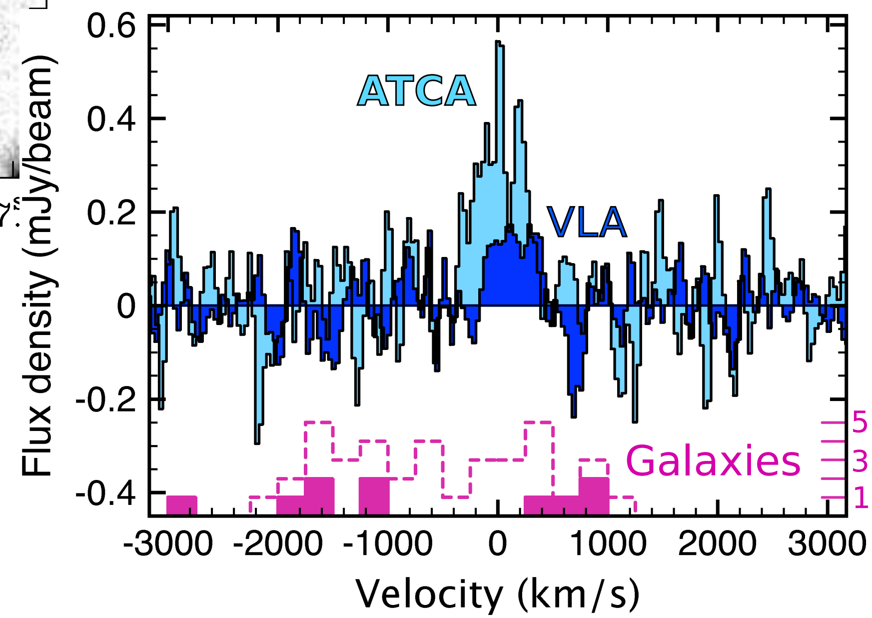
Spiderweb Galaxy: Cold Molecular IGM

low-surface-brightness emission!

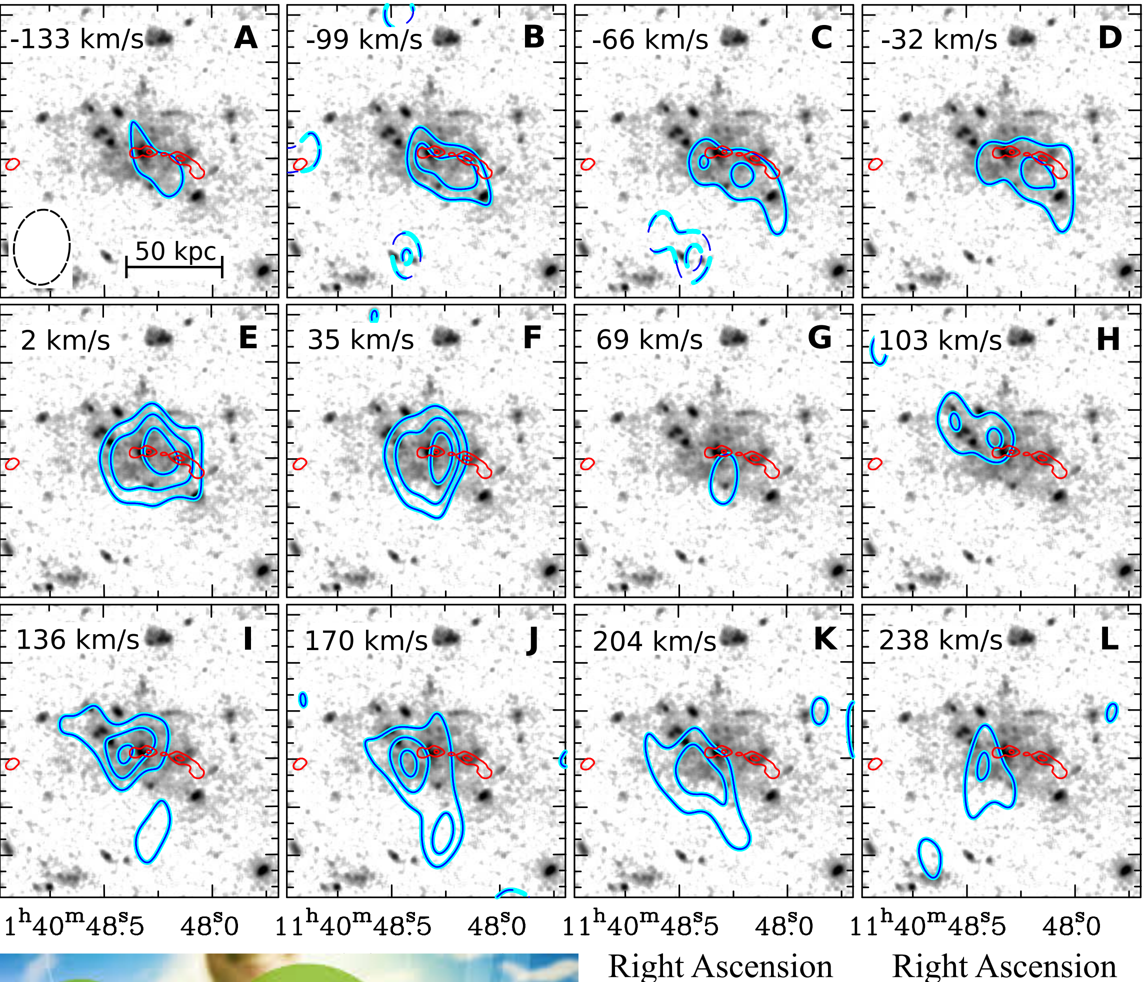


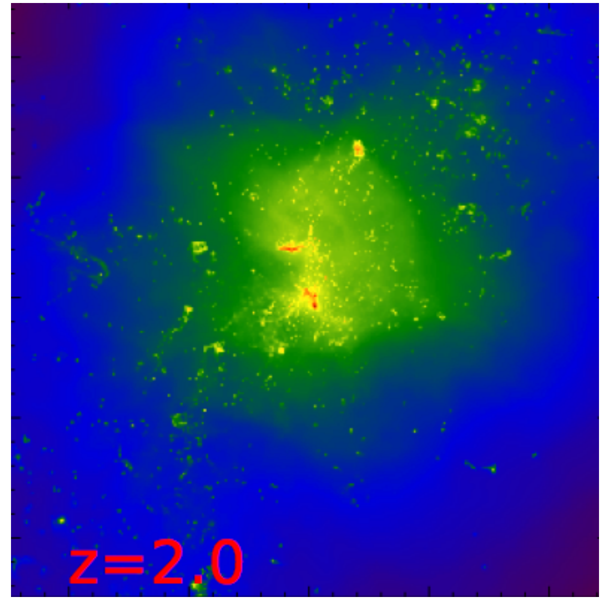
Emonts … HD et al. 2016, Science

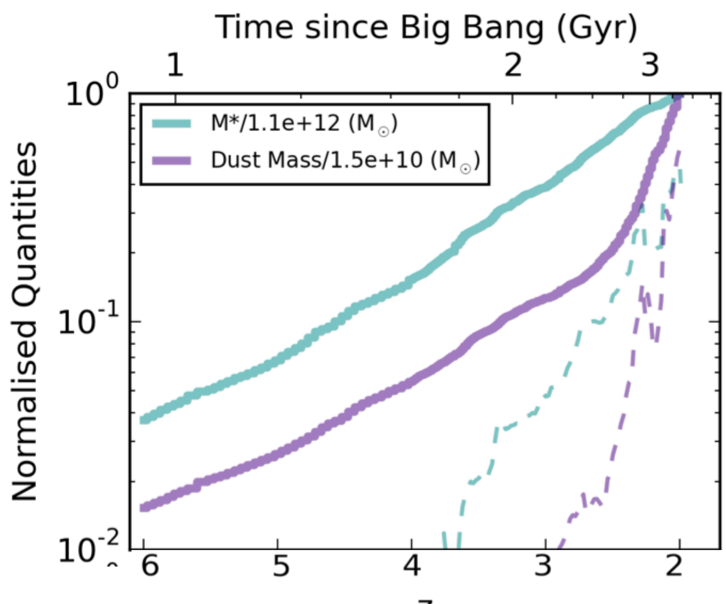
VLA sees only ~33% of ATCA flux!!



SW condensed directly from the cold gas



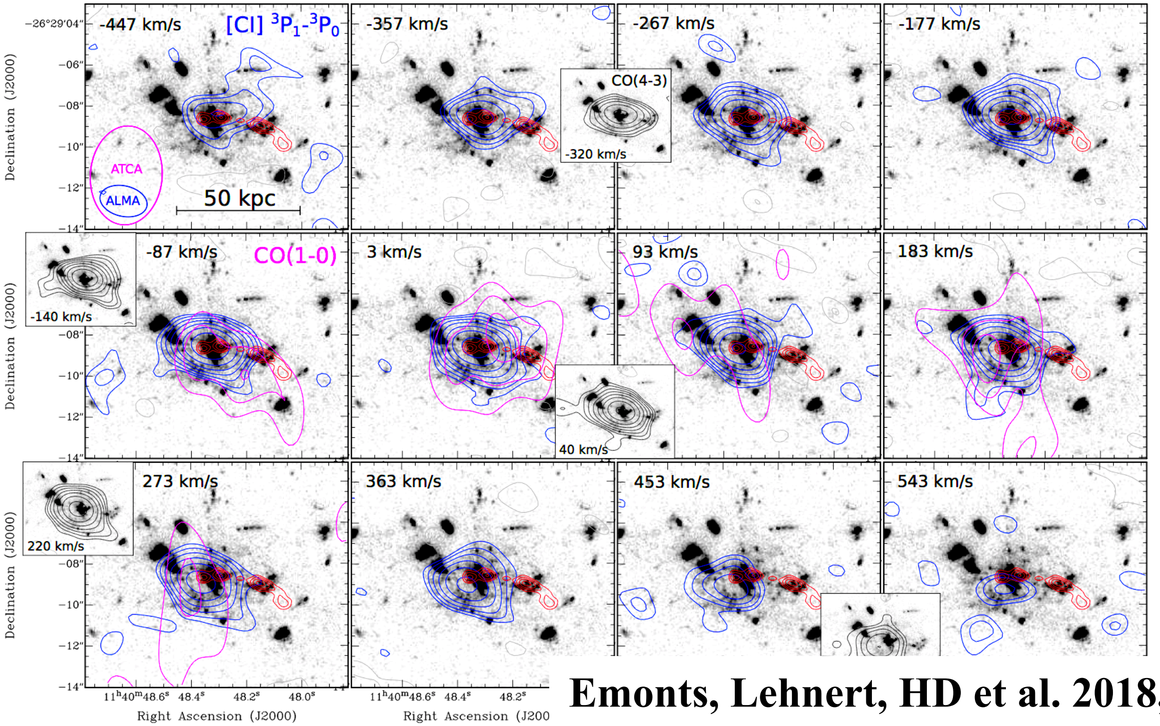




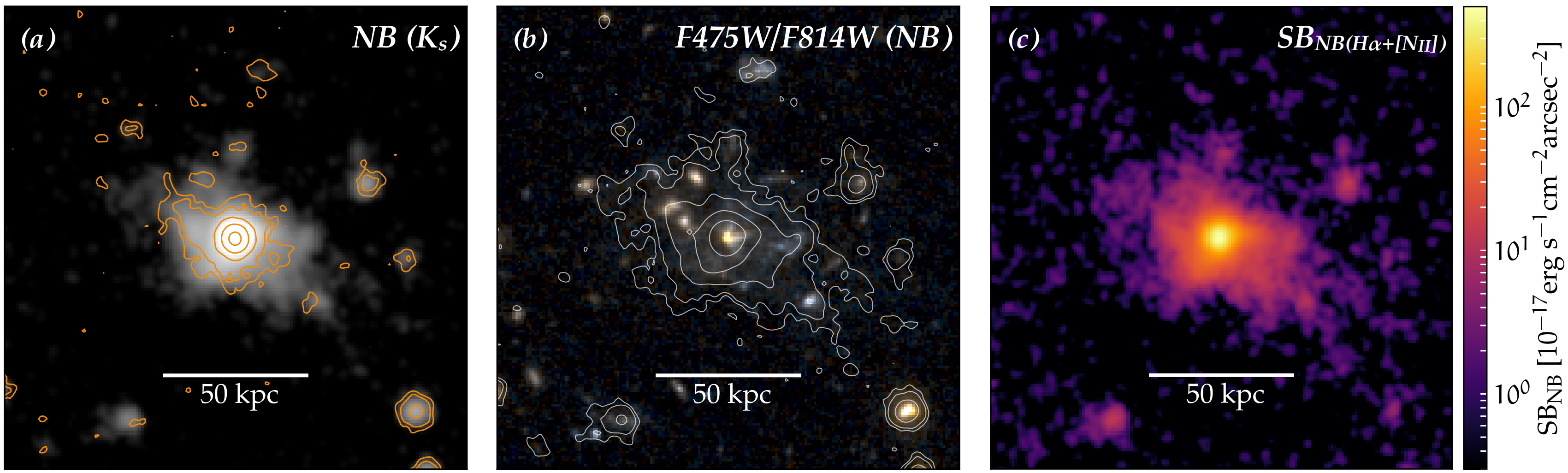
recycled gas!

Narayanan et al. 2015

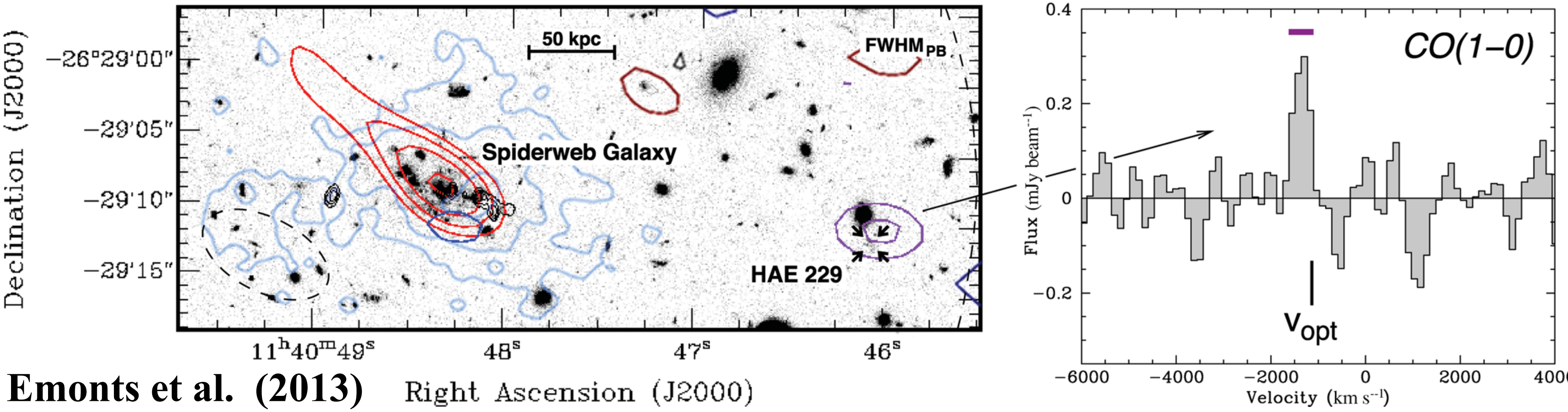
Extended Cold IGM



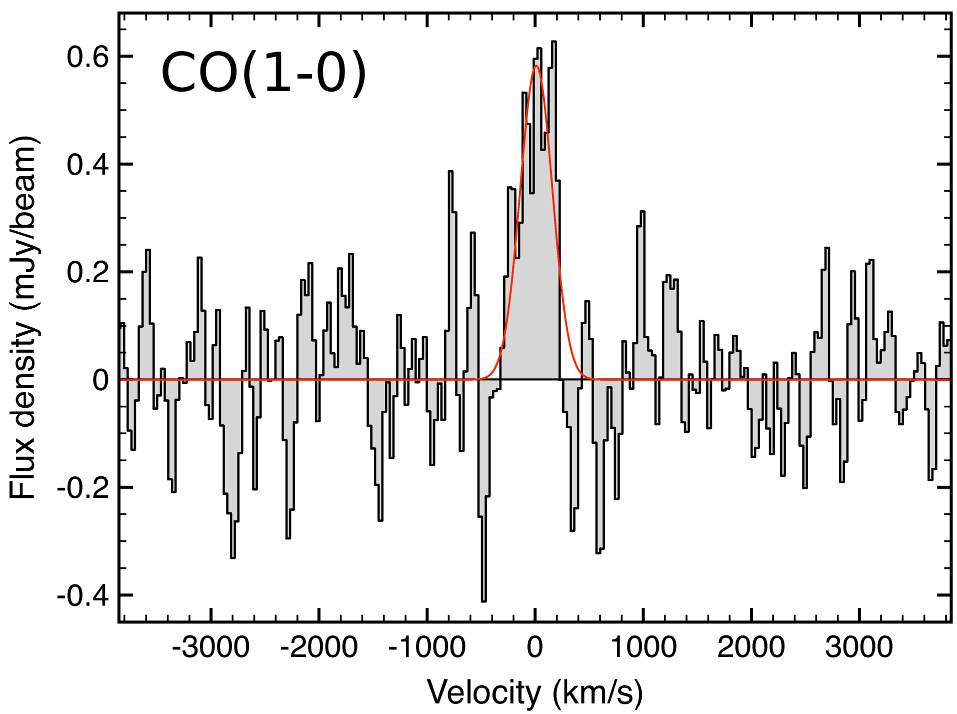
Emonts, Lehnert, HD et al. 2018, MNRAS, 477, 60



Shimakawa … HD et al. 2018, MNRAS, submitted

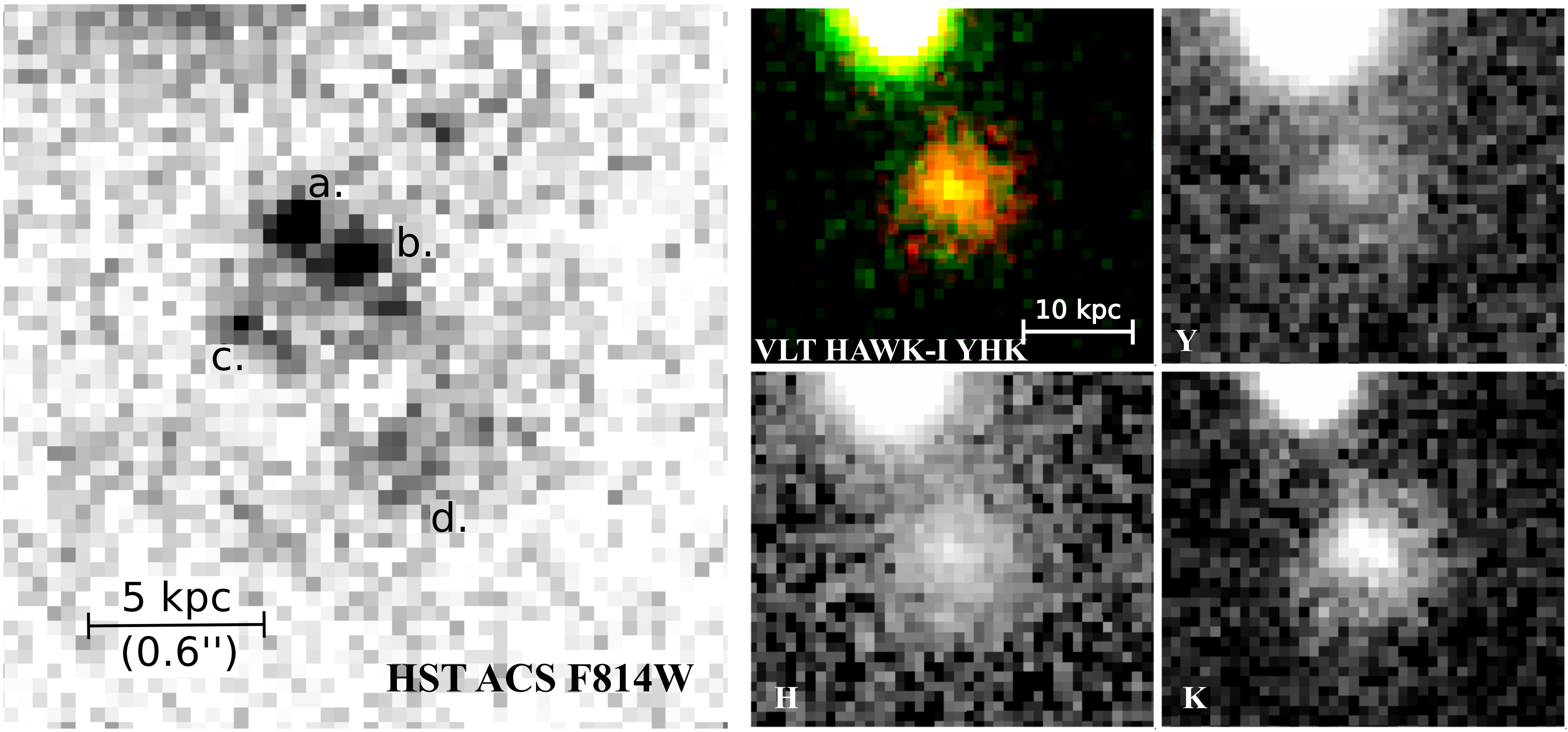


Emonts et al. (2013)



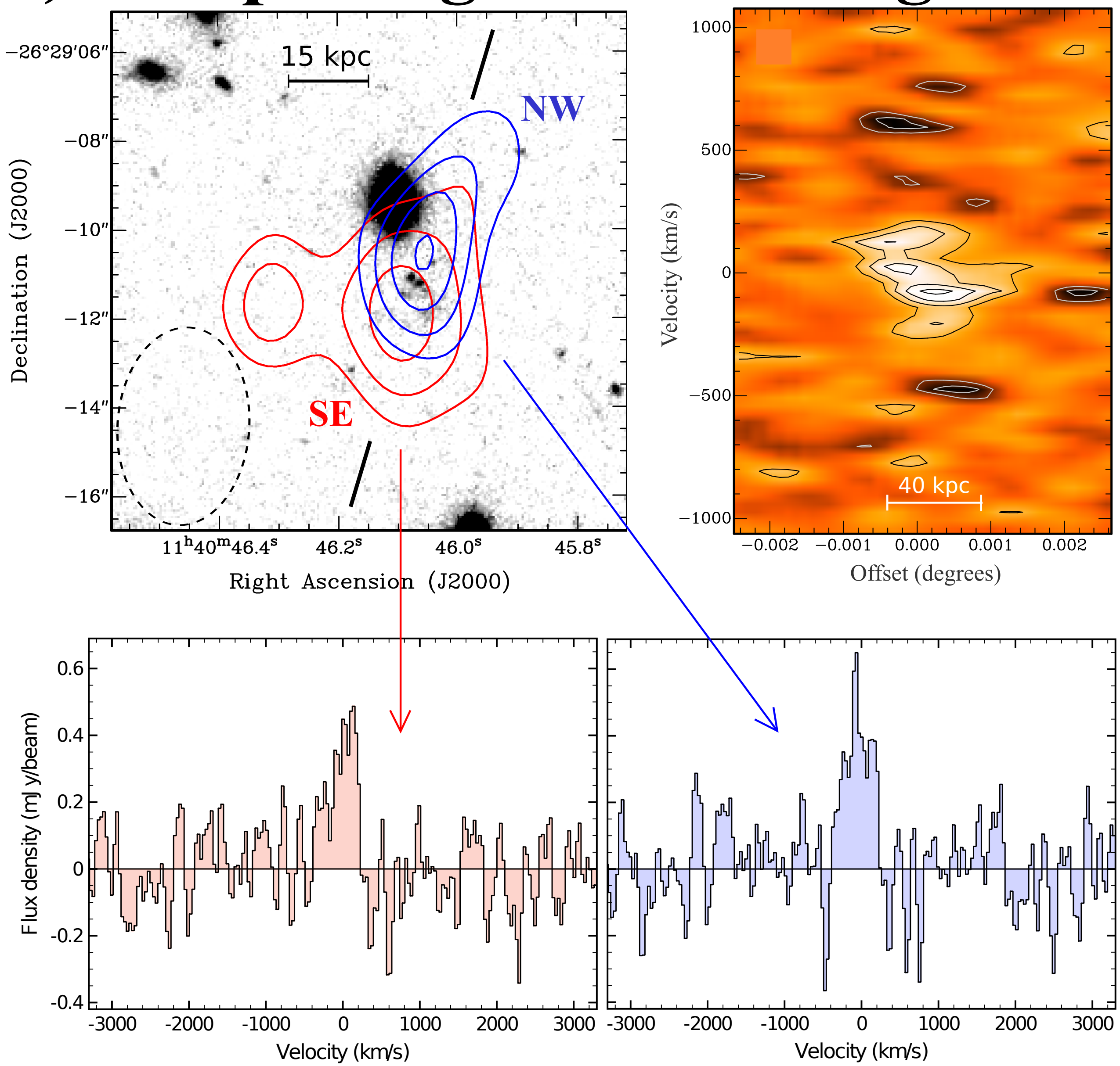
Dannerbauer, Lehnert, Emonts et al. 2017, A&A, 608, 48

HAE229: morphology



Dannerbauer, Lehnert, Emonts et al. 2017, A&A, 608, 48

CO(1-0): 40kpc large molecular gas reservoir



Dannerbauer, Lehnert, Emonts et al. 2017, A&A, 608, 48

Literature

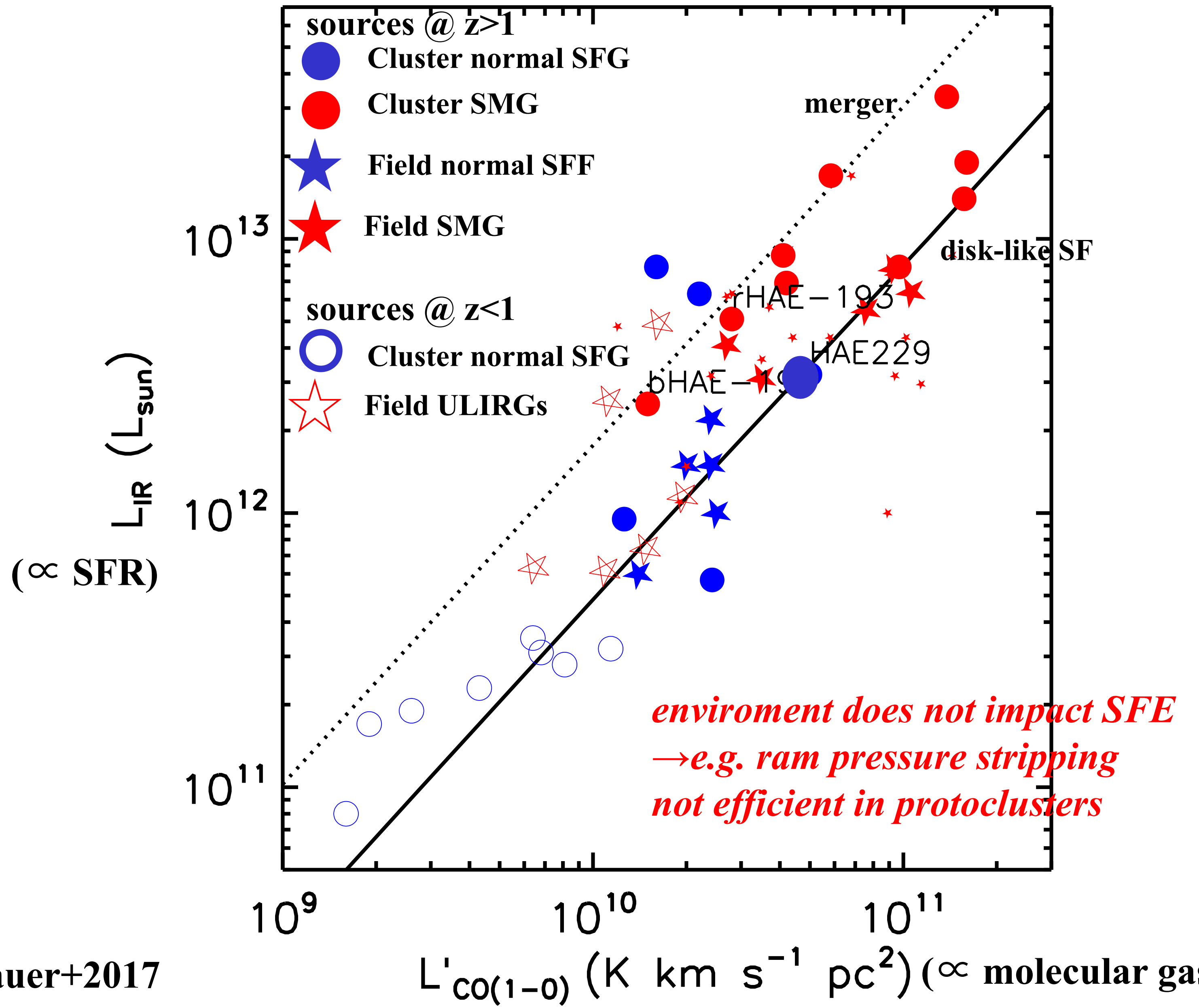
January 2017

Table A.1. CO observations of $z > 0.4$ cluster members.

Name	z_{CO}	Transition	I_{CO} (Jy km′)	FWHM (km s^{-1}	Telescope	L'_{CO} (10^{10} K km s^{-1} pc^2)	L_{IR} (10^{12})	Reference
Cluster Cl0024+16 at z = 0.40								
MIPS J002652.5	0.3799	1 − 0		140 ± 10	PdBI	0.64 ± 0.05	3.5 ± 0.5	Geach et al. (2011)
MIPS J002621.7	0.3803	1 − 0		144 ± 14	PdBI	0.68 ± 0.06	3.1 ± 0.2	Geach et al. (2009)
MIPS J002715.0	0.3813	1 − 0		340 ± 40	PdBI	0.26 ± 0.03	1.9 ± 0.3	Geach et al. (2011)
MIPS J002703.6	0.3956	1 − 0		250 ± 30	PdBI	0.43 ± 0.06	2.3 ± 0.3	Geach et al. (2011)
MIPS J002721.0	0.3964	1 − 0		158 ± 34	PdBI	1.14 ± 0.11	3.2 ± 0.2	Geach et al. (2009)
Cluster Cl1416+4446 at z = 0.40								
GAL1416+446	0.3964	1 − 0	1.0 ± 0.1	420 ± 40	PdBI	0.81 ± 0.8	0.275	Jablonka et al. (2013)
Cluster Cl09266+1242 at z = 0.49								
GAL0926+1242−A	0.4886	2 − 1	0.6 ± 0.1	420 ± 40	PdBI	0.19 ± 0.03	0.165	Jablonka et al. (2013)
GAL0926+1242−B	0.4886	2 − 1	0.5 ± 0.1	200 ± 20	PdBI	0.16 ± 0.03	0.082	Jablonka et al. (2013)
Cluster 7C 1756+6520 at z = 1.42								
AGN.1317	1.4161 ± 0.0001	2 − 1	0.52 ± 0.06	254 ± 33	PdBI	1.36 ± 0.15		Casasola et al. (2013)
Cluster COSMOS at z = 1.55								
51613	1.517	1 − 0	0.20 ± 0.05	200 ± 80	VLA	2.42 ± 0.58	0.57	Aravena et al. (2012)
51858	1.556	1 − 0	0.10 ± 0.03	360 ± 220	VLA	1.26 ± 0.38	0.95	Aravena et al. (2012)
protocluster MRC 1138−262 at z = 2.16								
HAE229	2.1480 ± 0.0004	1 − 0	0.22 ± 0.02	359 ± 34	ATCA	5.0 ± 0.7	3.2	**this paper**
protocluster HATLAS J084933 at z = 2.41								
HATLAS J084933 W	2.4066 ± 0.0006	1 − 0	0.49 ± 0.06	825 ± 115	VLA	13.8 ± 1.7	$33.1^{+3.2}_{-2.9}$	Ivison et al. (2013)
HATLAS J084933 T	2.4090 ± 0.0003	1 − 0	0.56 ± 0.07	610 ± 55	VLA	15.7 ± 2.0	$14.5^{+1.8}_{-1.6}$	Ivison et al. (2013)
HATLAS J084933 M	2.4176 ± 0.0004	1 − 0	0.057 ± 0.013	320 ± 70	VLA	1.6 ± 0.4	$7.9^{+4.6}_{-2.9}$	Ivison et al. (2013)
HATLAS J084933 C	2.4138 ± 0.0003	1 − 0	0.079 ± 0.014	250 ± 100	VLA	2.2 ± 0.4	$6.3^{+3.7}_{-2.3}$	Ivison et al. (2013)
protocluster USS 1558−003 at z = 2.51								
rHAE−193	2.5131	1 − 0	0.096 ± 0.015	437	VLA	2.8	5.1	Tadaki et al. (2014)
bHAE−191	2.5168	1 − 0	0.052 ± 0.008	251	VLA	1.5	2.5	Tadaki et al. (2014)
protocluster B3 J2330 at z = 3.09								
JVLA J233024.69+392708.6	3.0884 ± 0.0010	1 − 0	0.16 ± 0.03	720 ± 170	VLA	6.9 ± 1.5		Ivison et al. (2012)
protocluster GN20 at z = 4.05								
GN20	4.0548 ± 0.0008	2 − 1	1.0 ± 0.3	310 ± 110	VLA	16.0 ± 5.0	$18.6^{+0.9}_{-0.8}$	Hodge et al. (2012); Tan et al. (2014)
GN20.2a	4.051 ± 0.001	2 − 1	0.6 ± 0.2	830 ± 190	VLA	9.7 ± 2.9	$7.9^{+0.4}_{-0.9}$	Hodge et al. (2013a); Tan et al. (2014)
GN20.2b	4.056 ± 0.001	2 − 1	0.3 ± 0.2	400 ± 210	VLA	4.2 ± 2.9	$6.9^{+0.7}_{-1.4}$	Hodge et al. (2013a); Tan et al. (2014)
protocluster HDF850.1 at z = 5.18								
HDF850.1	5.183	2 − 1	0.17 ± 0.04	400 ± 30	VLA	4.1	8.7 ± 1.0	Walter et al. (2012)
protocluster AzTEC-3 at z = 5.30								
AzTEC−3	5.2979 ± 0.0004	2 − 1	0.23 ± 0.03	487 ± 58	VLA	5.84 ± 0.78	17 ± 8	Riechers et al. (2010)

Dannerbauer+2017

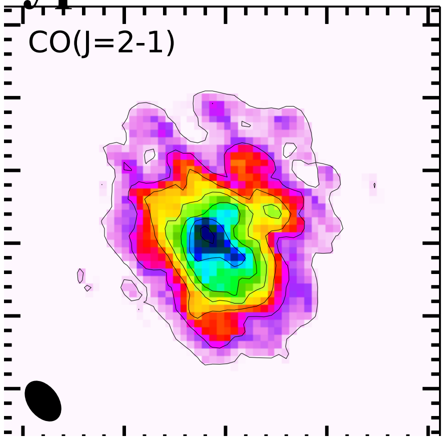
Impact of Environment: star-formation law

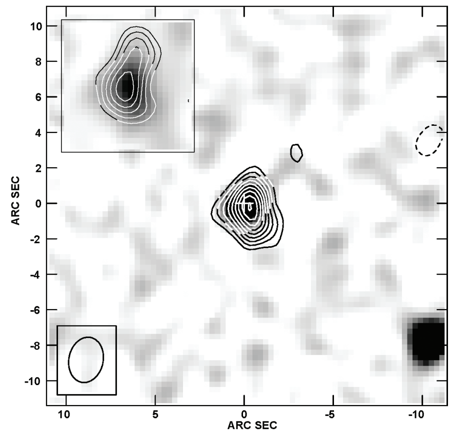


Dannerbauer+2017

Sizes of Molecular Gas Reservoirs

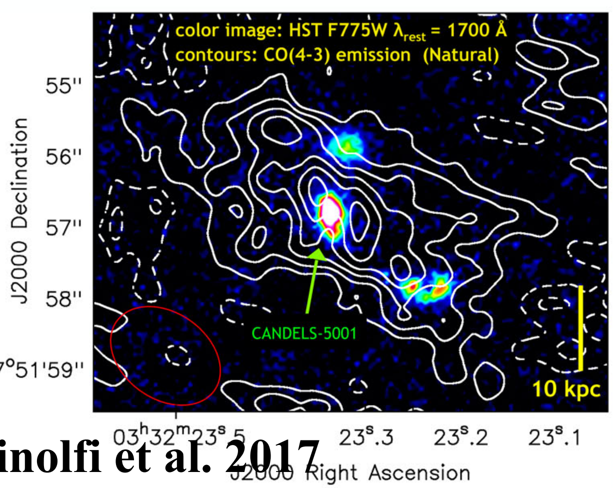
typical sizes are up to 6-8 kpc



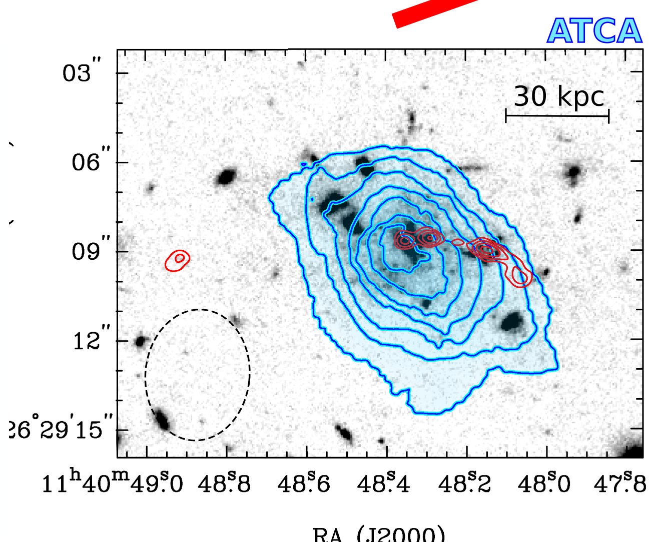


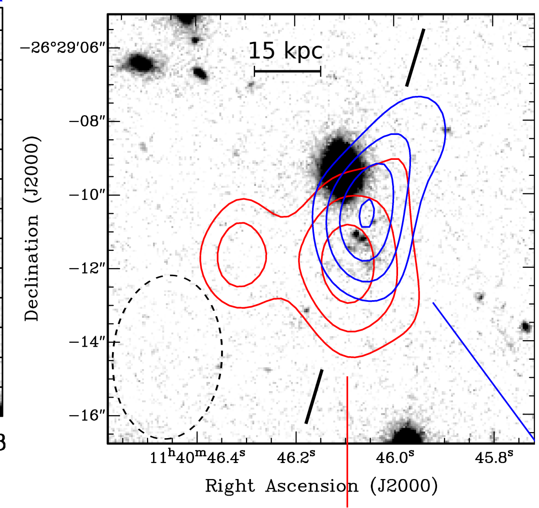
Hodge et al. 2015; Ivison et al. 2011

large molecular gas reservoirs could feed the ICM through truncation



Ginolfi et al. 2017





COALAS

CO ATCA Legacy Archive of Star-Forming Galaxies

- **ATCA Large Program (PI: Dannerbauer) from 04/17–09/19**
- **Team: Bjorn Emonts, Alaisdair Thomson, Ian Smail, Minh Huynh, James Allison, Bruno Altieri, Itziar Aretxaga, Niel Brandt, Scott Chapman, Caitlin Casey, Jackie Champagne, Carlos De Breuck, Guillaume Drouart, Jackie Hodge, Balt Indermuehle, Shuowen Jin, Amy Kimball, Tadayuki Kodama, Yusei Koyama, Claudia Lagos, Matthew D. Lehnert, George Miley, Desika Narayanan, Ray Norris, Huub Roettgering, James Simpson, Eva Schinnerer, Nick Seymour, Rhythm Shimakawa, Mark Swinbank, Ivan Valtchanov, Fabian Walter, Julie Wardlow**
- **640 hrs awarded (already 490hrs observed, 21 Feb 2019)**
- **CO(1-0) observations of 20 (dusty) star-forming galaxies**
- **selected from the Spiderweb Protocluster field and ALESS (APEX-LABOCA survey of the Extended Chandra Deep Field South) blank field**
- **complementing ALMA molecular gas and dust observation**

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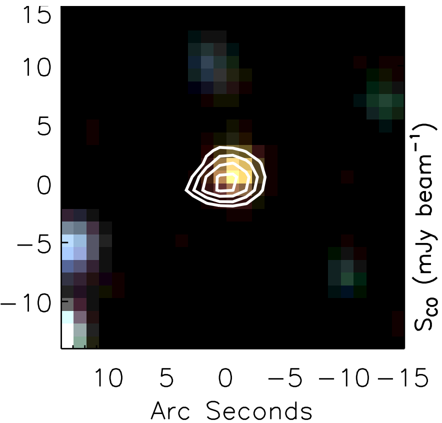
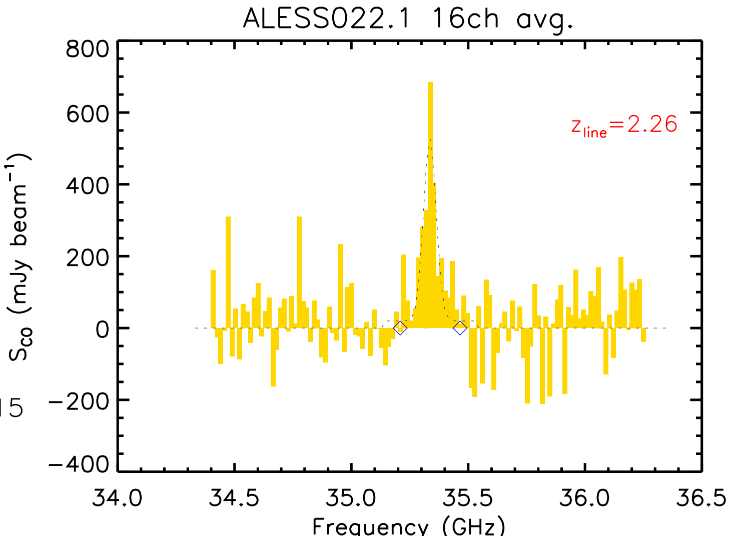
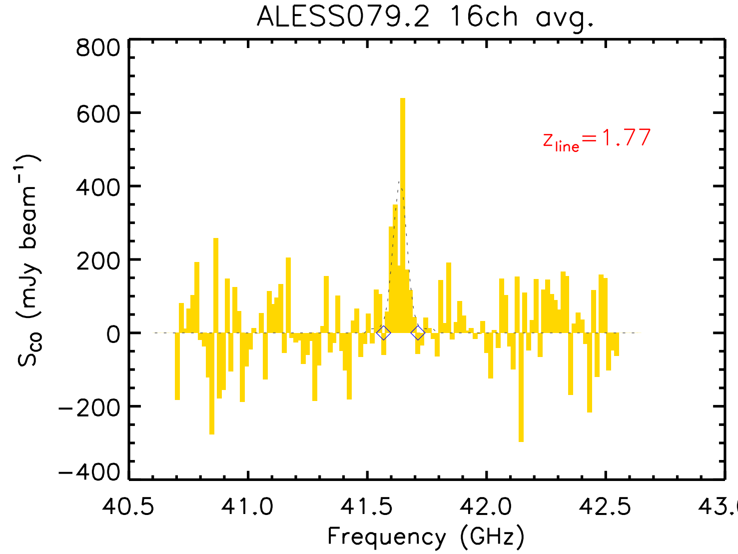
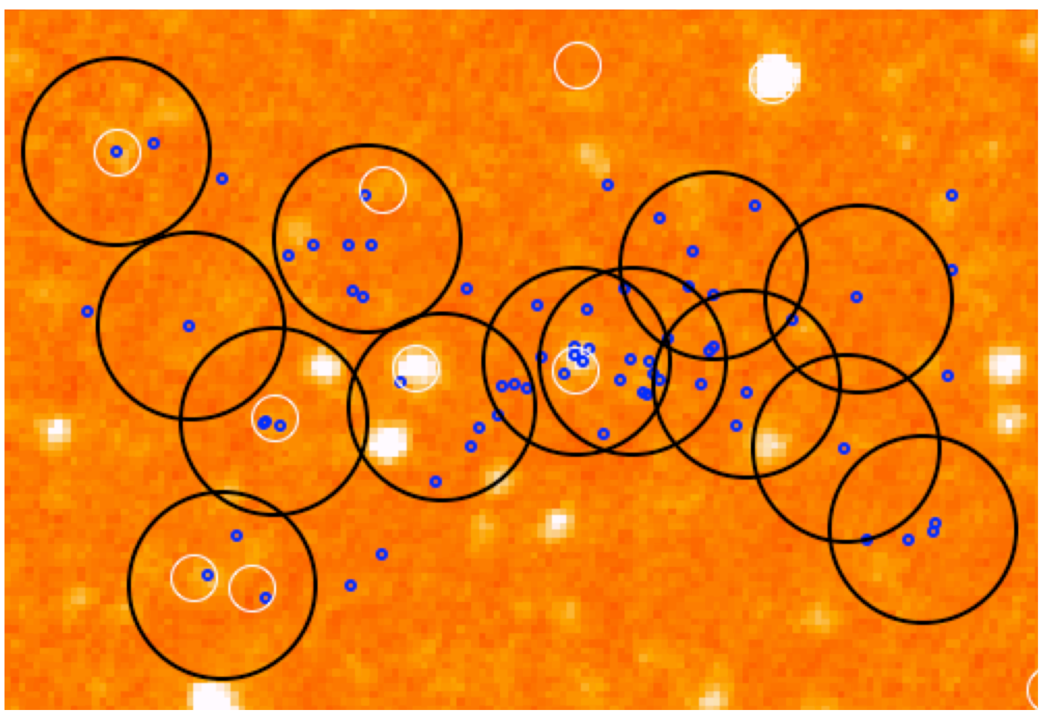
COALAS

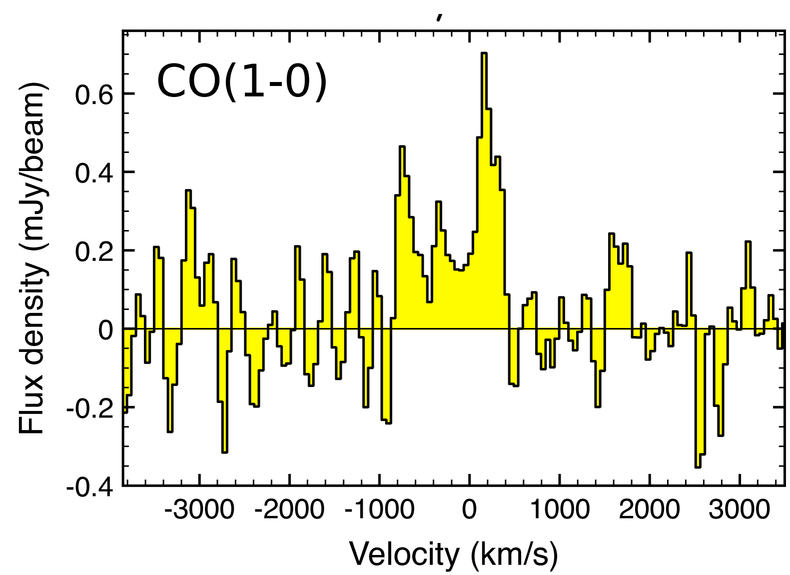






Thomson, Dannerbauer et al., in prep.





Conclusion

- LABOCA (submm) imaging seems to be a good way to search for overdensities/large scale structures

- two large molecular gas reservoirs discovered, unseen before

- BCG in formation seems to condensed from cold gas cloud

- our results suggest that environment does not impact the "star-formation efficiency" or the molecular gas content of high-redshift galaxies.

- ATCA LP molecular gas follow-up z=2 cluster&field galaxies

➔*Dannerbauer, Kurk, De Breuck et al., 2014, A&A, 570, 55*
➔*Emonts, Lehnert, Villar-Martin et al., 2016, Science, 354, 1128*
➔*Dannerbauer, Lehnert, Emonts et al., 2017, A&A, 608, 48*
➔*Emonts, Lehnert, Dannerbauer et al., 2018, MNRAS, 477, 60*
➔*Shimakawa …HD et al., 2018, MNRAS, 481, 5630*
➔*Dannerbauer et al. 2019, AJ, in press (astro-ph/1812.03845)*