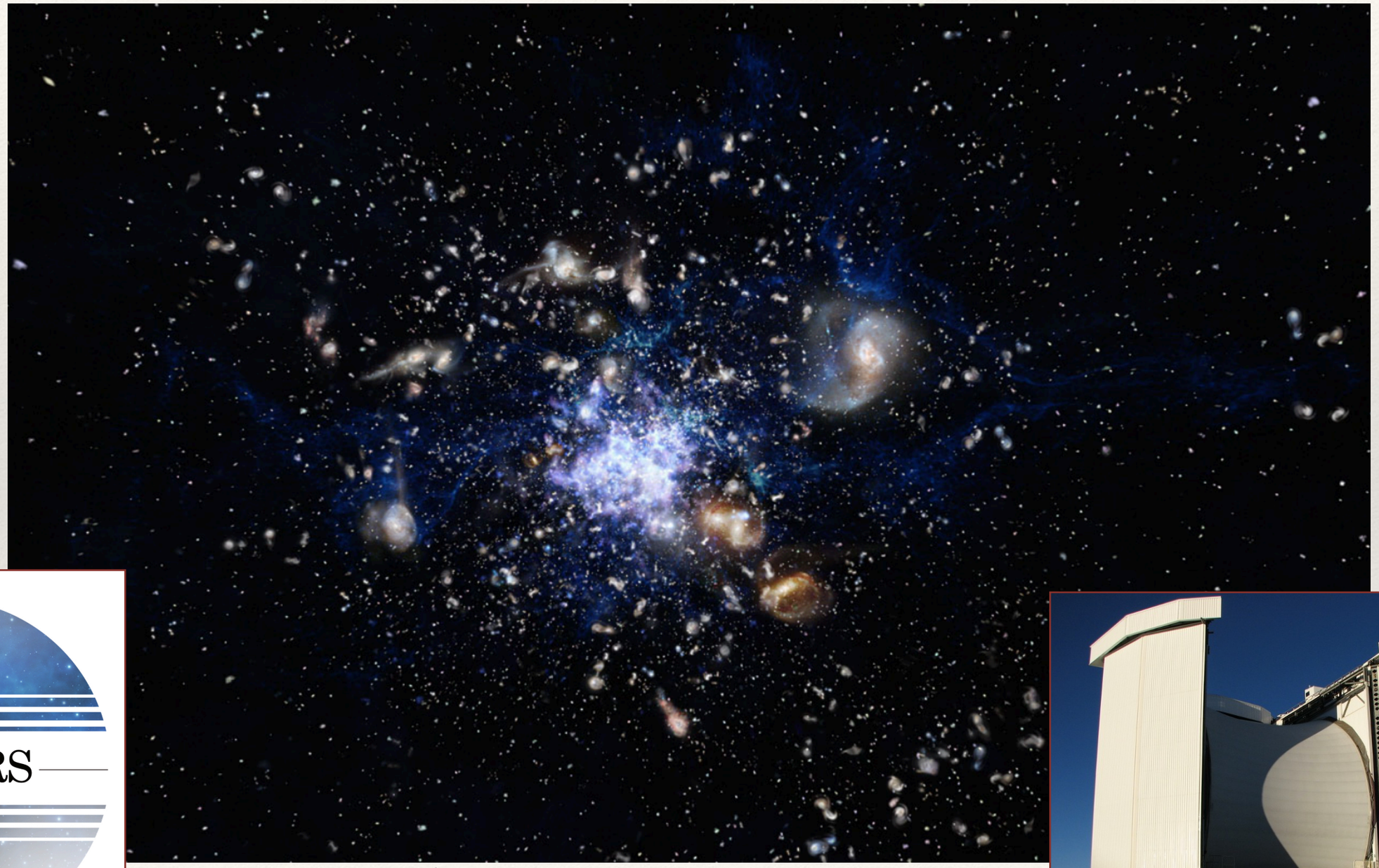
RAGERS - The RAdio Galaxy Environment Reference Survey

Thomas R. Greve (UCL/DAWN-DTU) t.r.greve@gmail.com
+ the rest of the RAGERS Team t



Credit: ESO/M. Kornmesser

RAGERS

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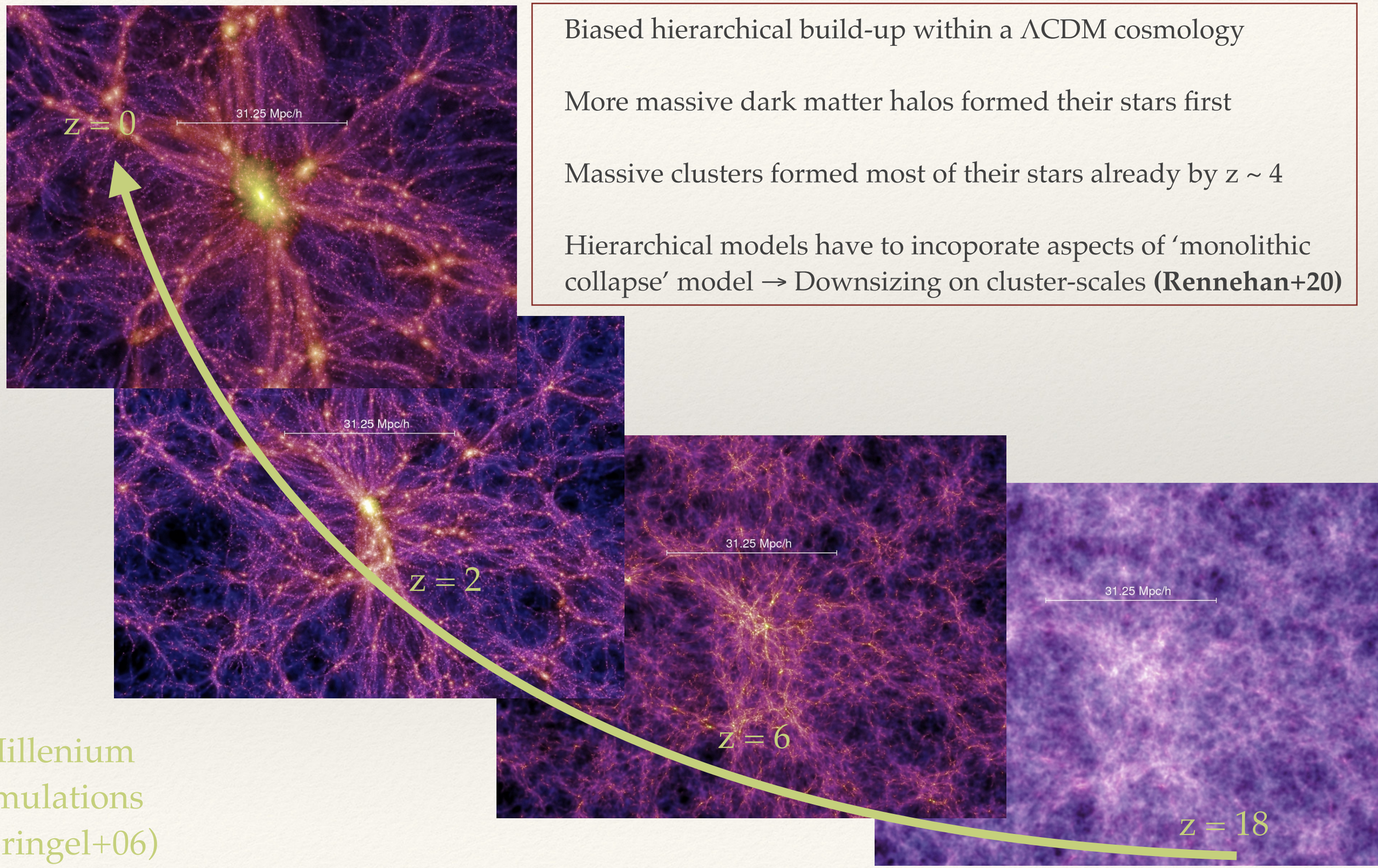
OUTLINE

- Motivation
- RAGERS in a Nutshell
- Status & Preliminary Results
- Followup Efforts

Credit: ESO/M. Kornmesser

RAGERS

Cosmic Structure Formation



Biased hierarchical build-up within a ΛCDM cosmology

More massive dark matter halos formed their stars first

Massive clusters formed most of their stars already by z ~ 4

Hierarchical models have to incoporate aspects of 'monolithic collapse' model → Downsizing on cluster-scales **(Rennehan+20)**

Millenium simulations (Springel+06)

Chiang+17

Thesaurus: Clusters and Protoclusters

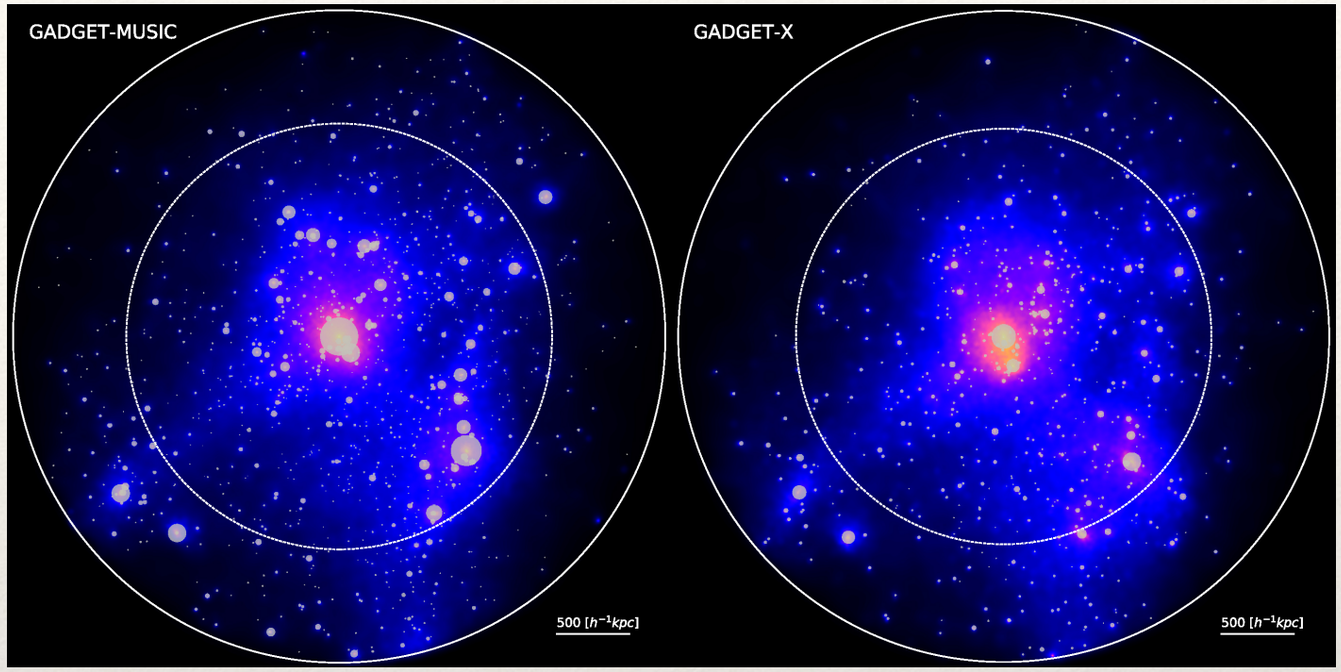
Theoretical Definition (credit: Roderik Overzier)

Cluster: a virialized object with a mass $M > 10^{14} M\odot$

Protocluster: a volume that will collapse to form a $M > 10^{14} M\odot$ halo by (no later than) $z = 0$.

The total number density of clusters and protoclusters at any redshift = cluster abundance today

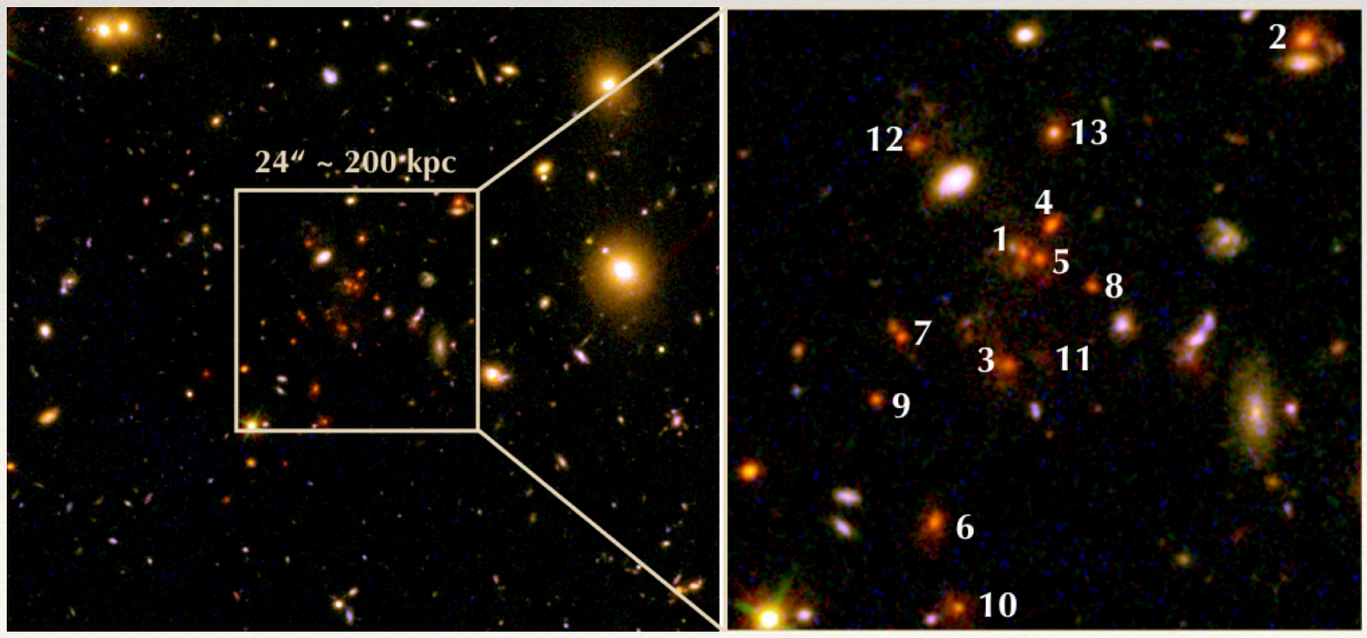
Protocluster core: … take your pick!



Weiguang+18

Other (empirical) defintions

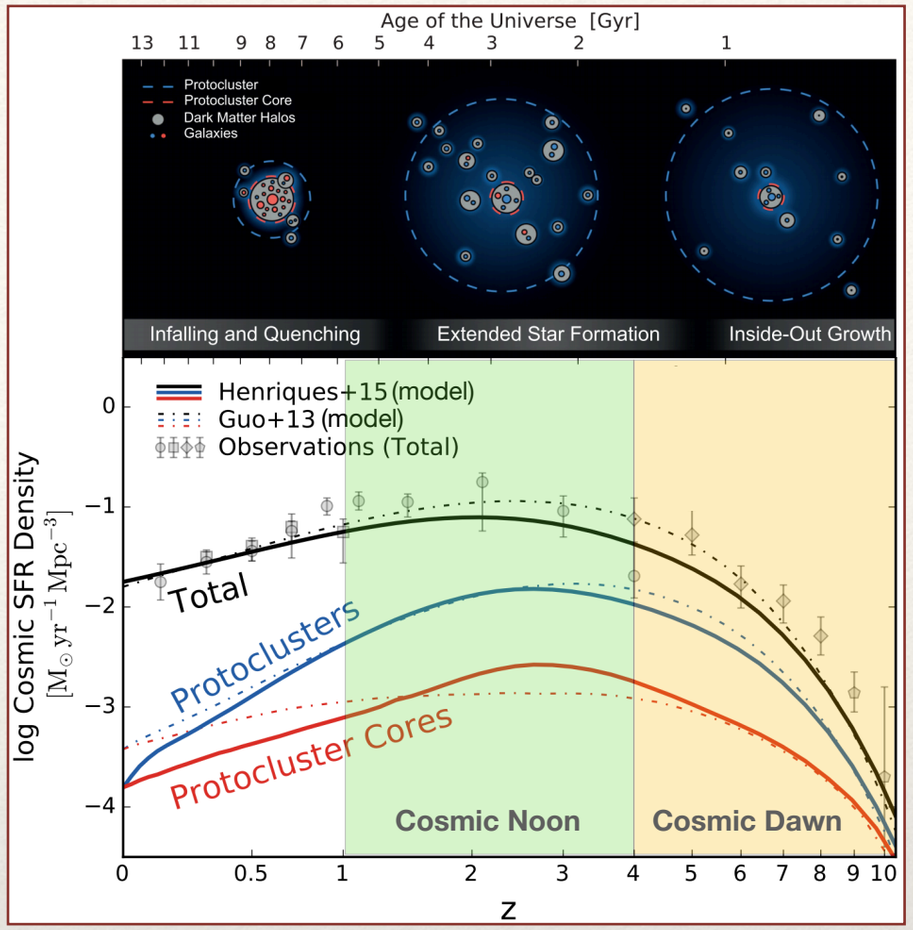
Morphology-density relation
Red sequence
X-ray ICM

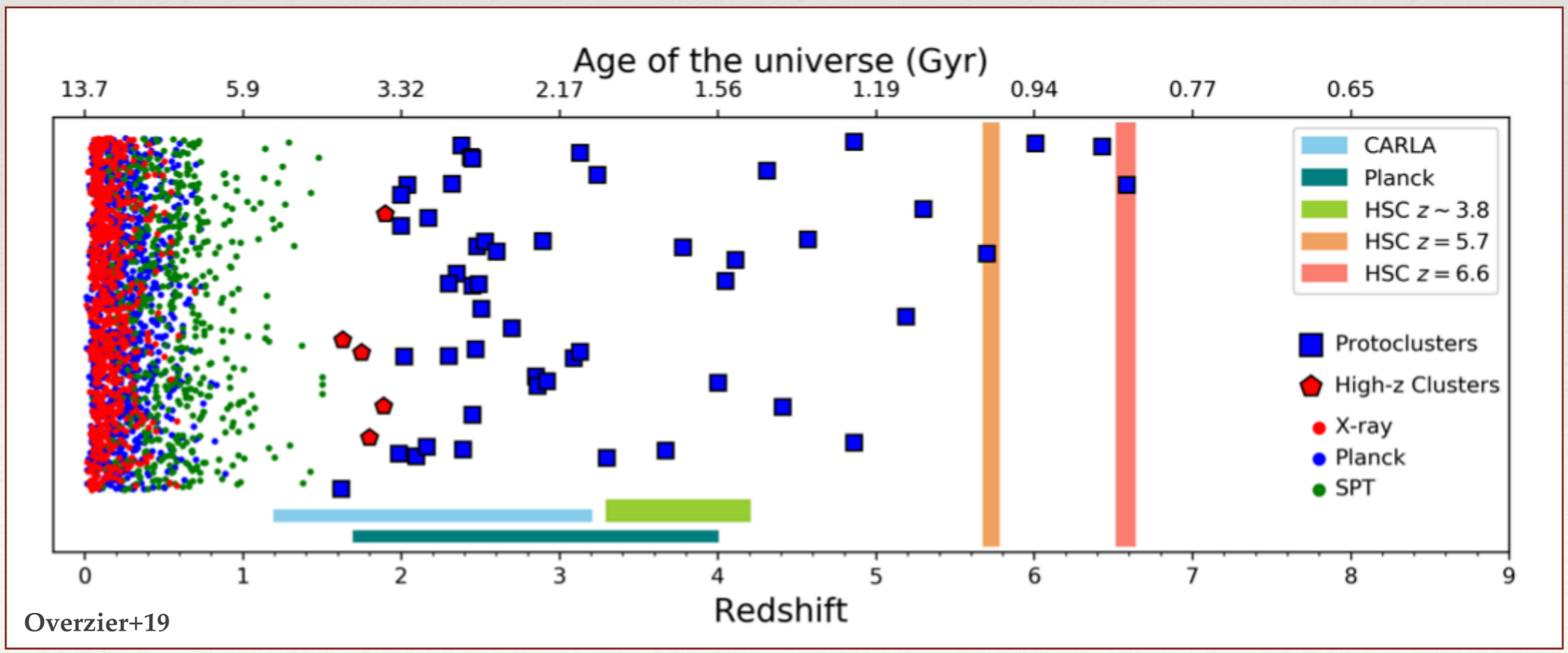


Strazzullo+16

Protoclusters and Overdensities

- NIR imaging
- X-ray selection
- Millimeter selection
- SZ effect
- Ly-alpha NB imaging
- Deep and large-area multi-wavelength OIR surveys
- Large spectroscopic surveys
- Targetting environments of massive AGN and QSO





Overzier+19

Protoclusters and Overdensities

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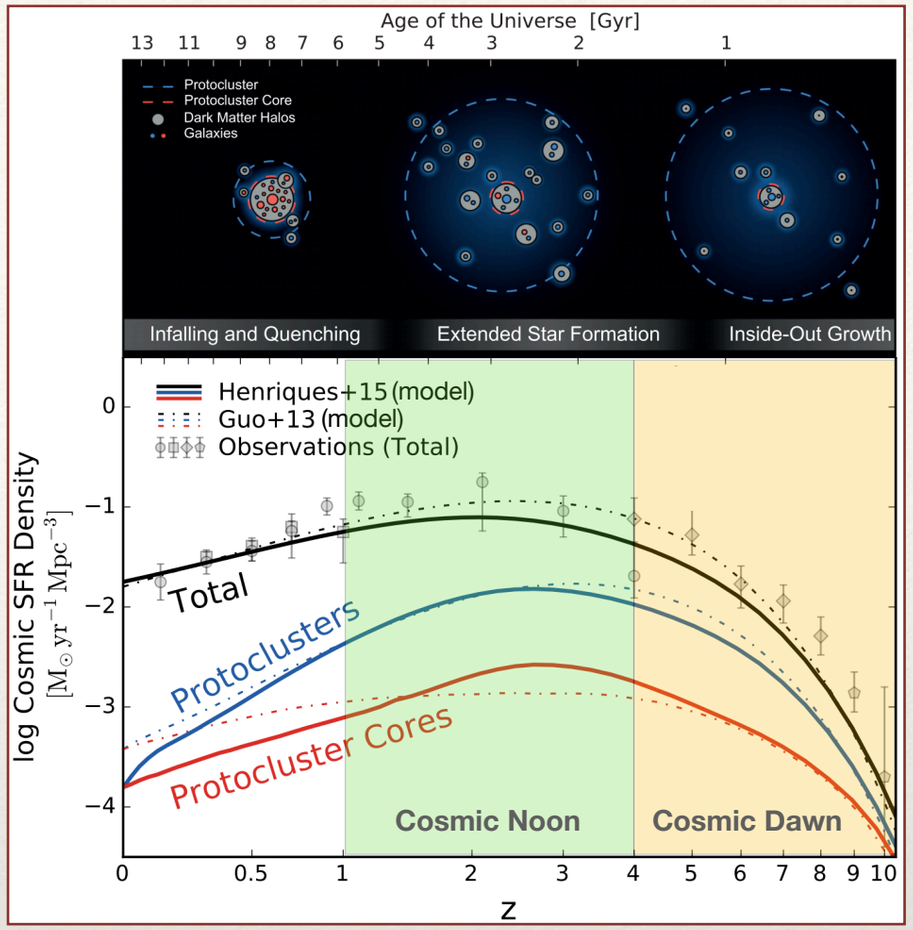
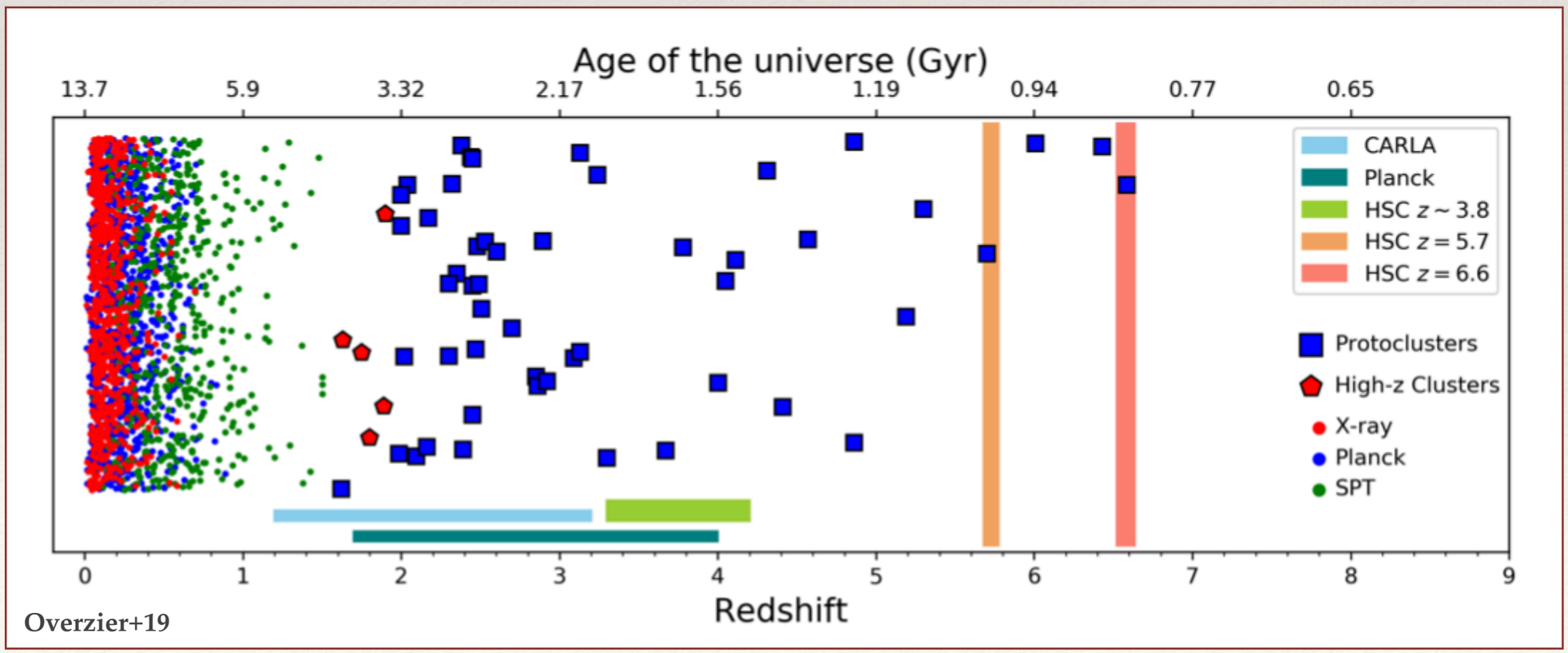
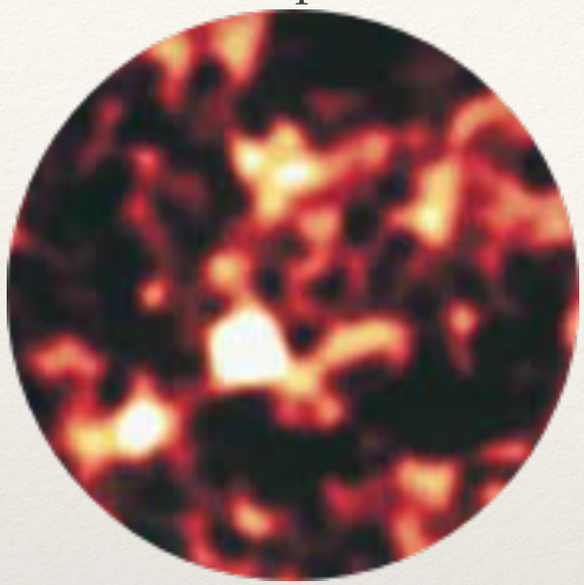




Overzier+19

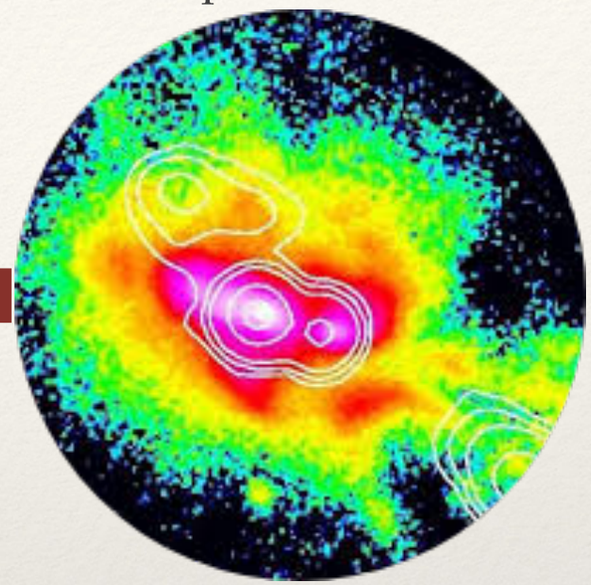
What is the SMG-HzRG Connection?

Bright SMGs become today's massive ellipticals

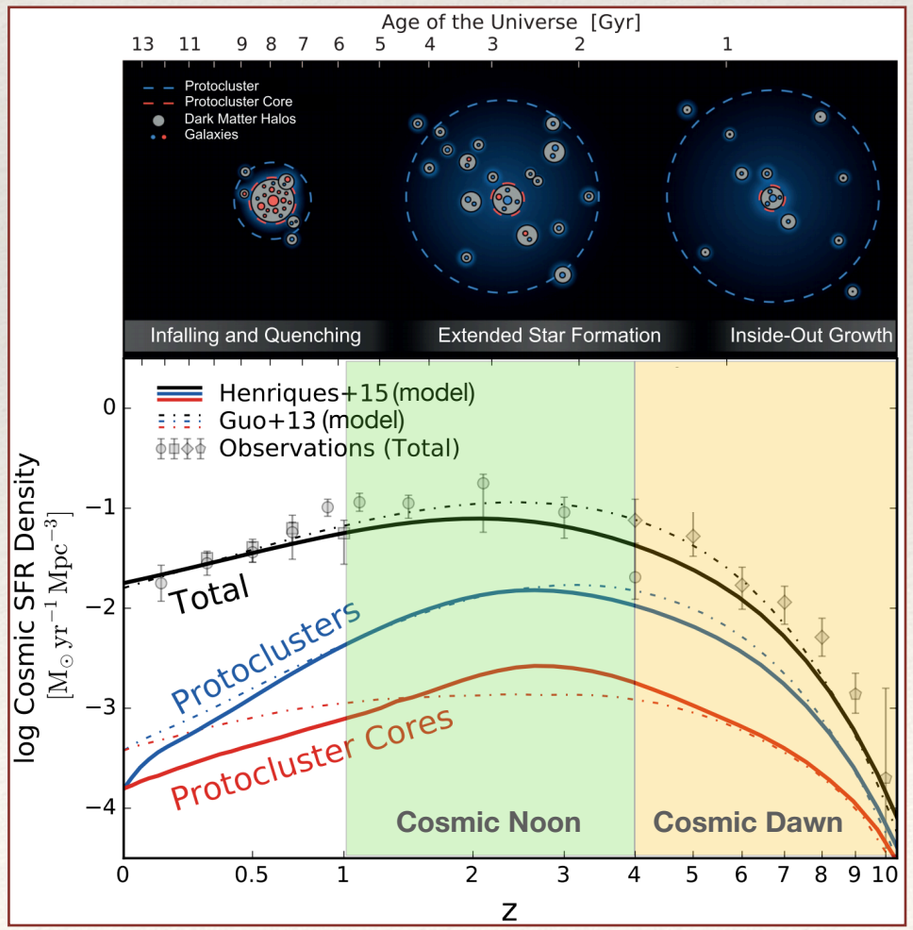


BCGs & Galaxy Clusters Today

High-z Radio Galaxies (HzRGs) beacons of protoclusters



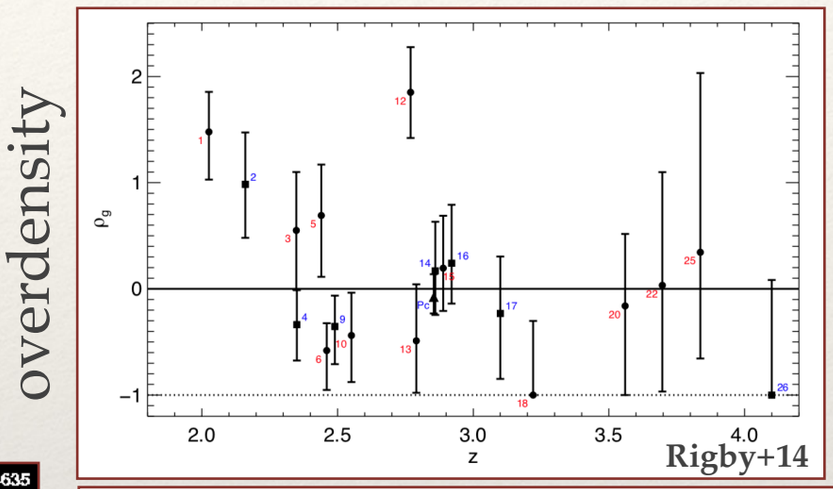
Expectation: an increase in SMG sources around HzRGs wrt the field — especially around Cosmic Noon where the Cosmic Starformation Density peaks.

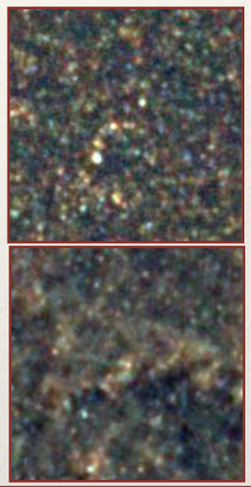


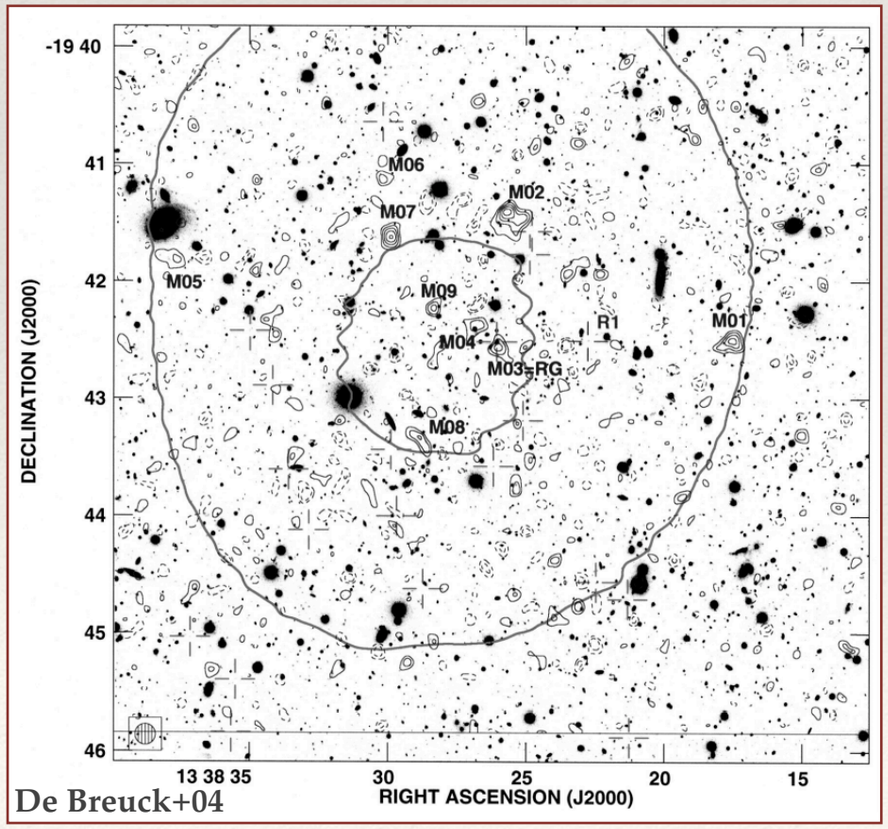
Chiang+17

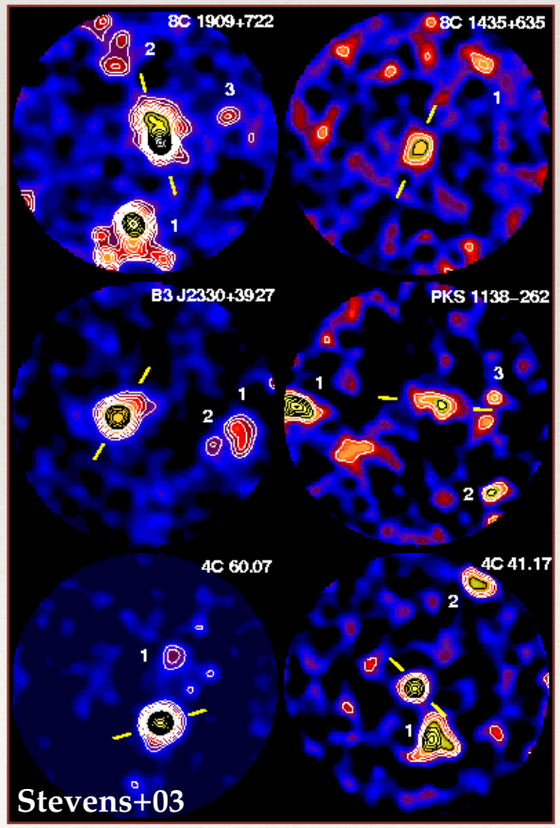
The Dusty Environments of HzRGs

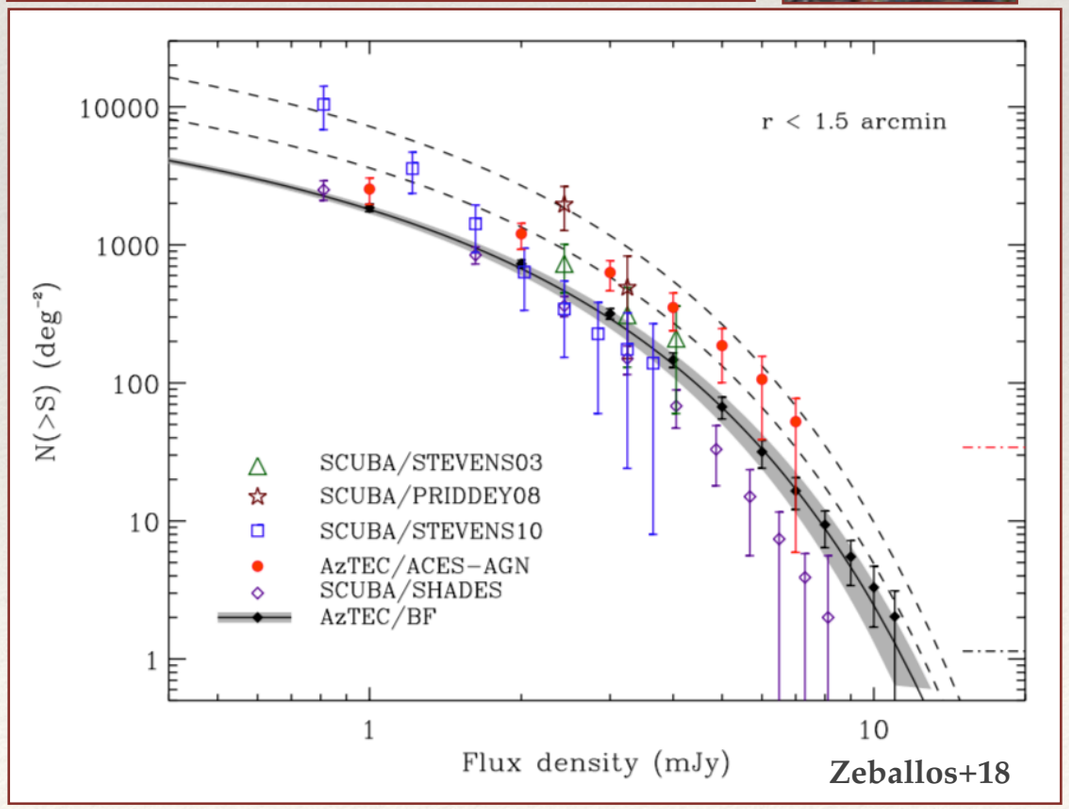
- High central SMG overdensities (~7× the field) in the most luminous HzRGs
- Follow-up studies of these extreme systems have lead to important new insights (See works by Jin, Lee, Gullberg, Dannerbauer)
- But moderate to no overdensity on less luminous HzRGs







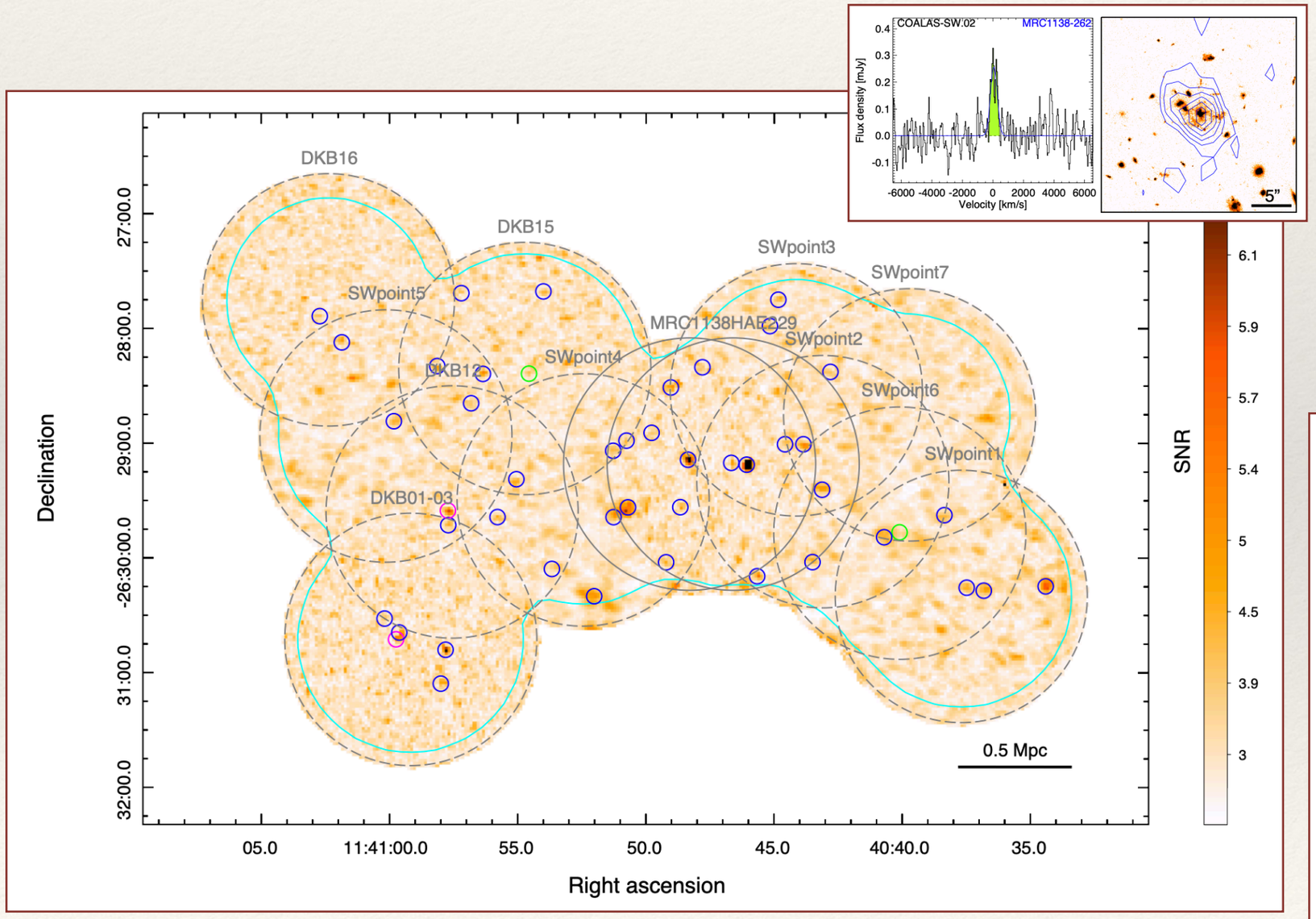


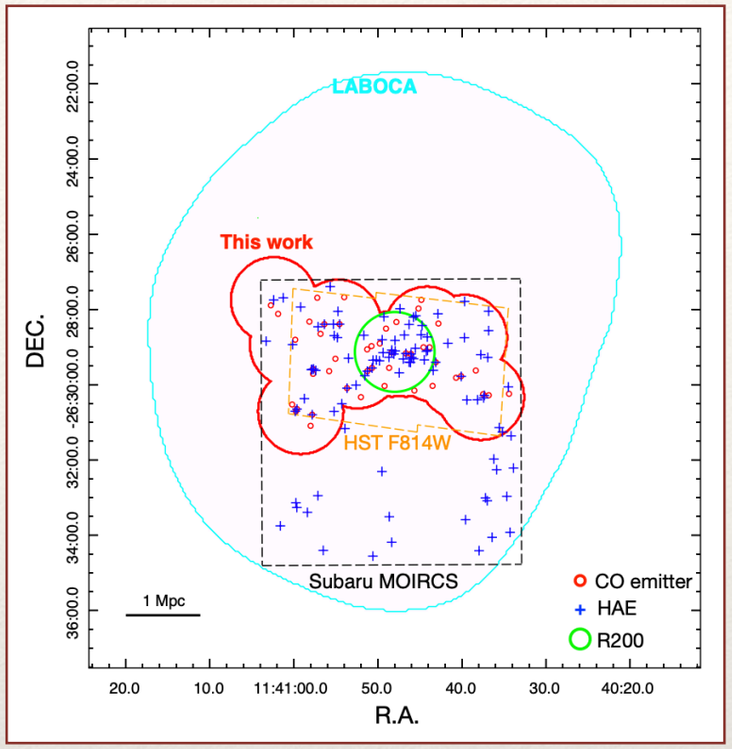


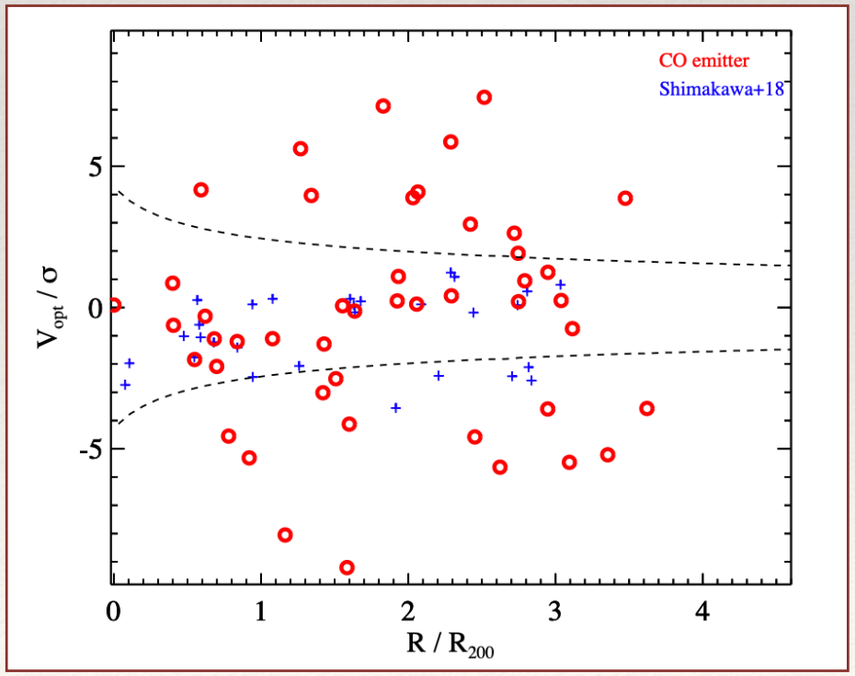
Ivison+00; Smail+03; Stevens+03+10; De Breuck+04; Greve+03+07; Humphrey+11; Carrera+11; Wylezalek+13; Rigby+14; Dannerbauer+14; Lee+17; Zeballos+18

The Dusty Environments of HzRGs

The z = 2.16 Spiderweb Galaxy - a Treasure Trove







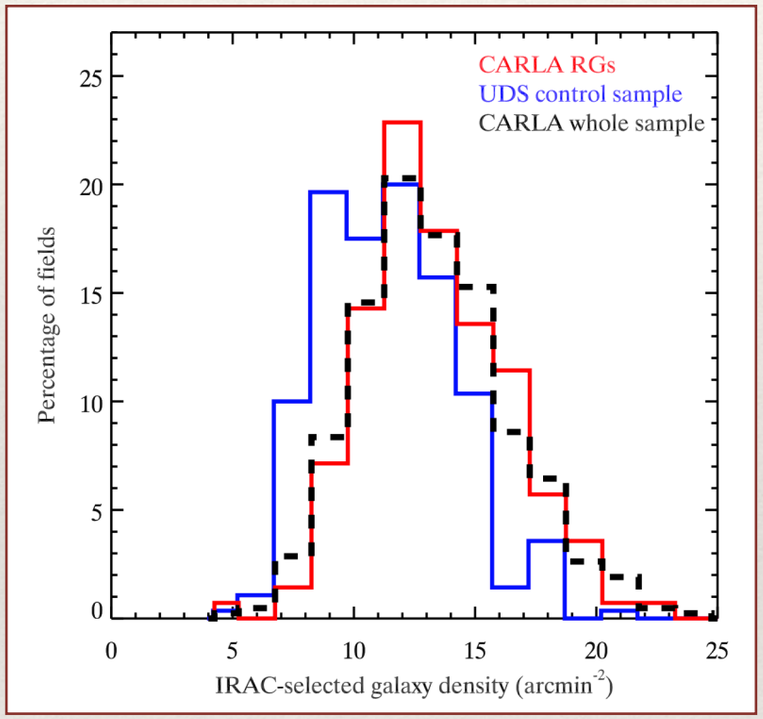
Stevens+03

Shouwen Jin+21

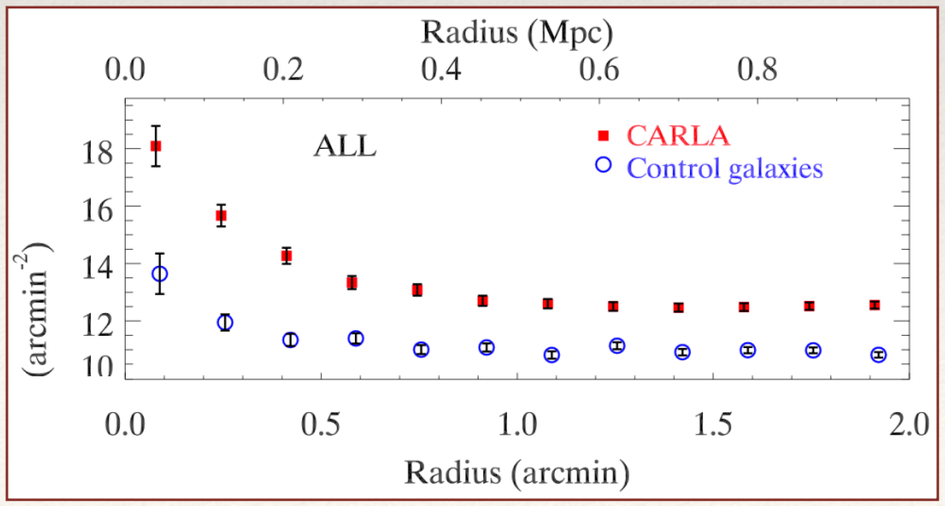
What is the AGN-Dense Environment Connection?

CARLA Survey

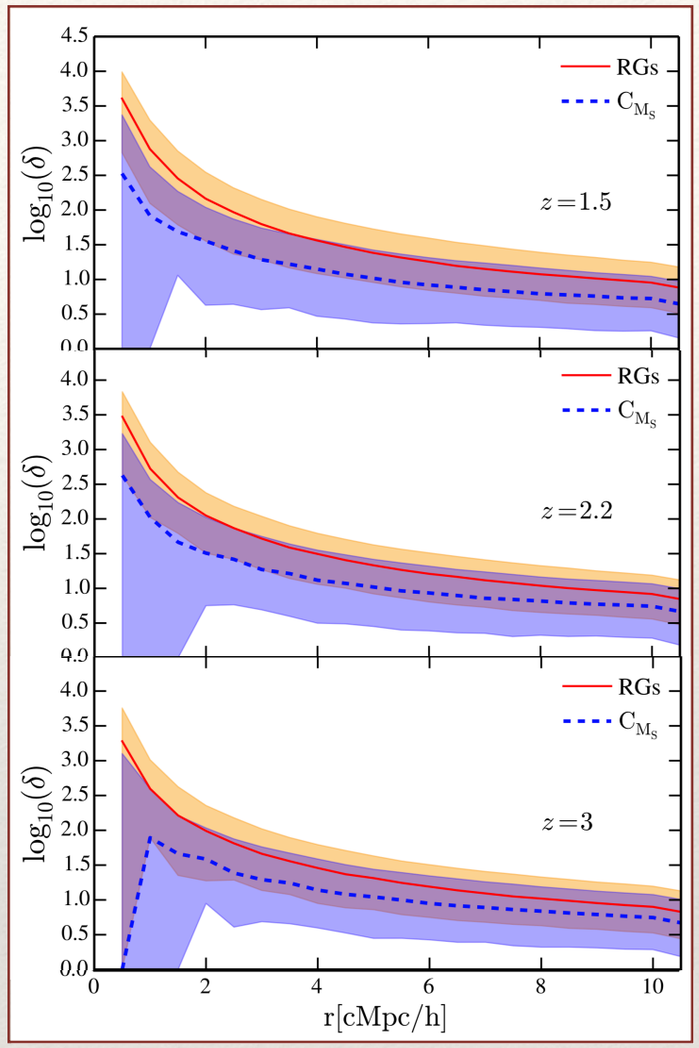
- RL-galaxies reside in IRAC-overdense environments compared to similar RQ-galaxies ($1.3 < z < 3.2$)
- 50% of massive galaxies undergo AGN feedback
- Launching of jet connected to dense environment



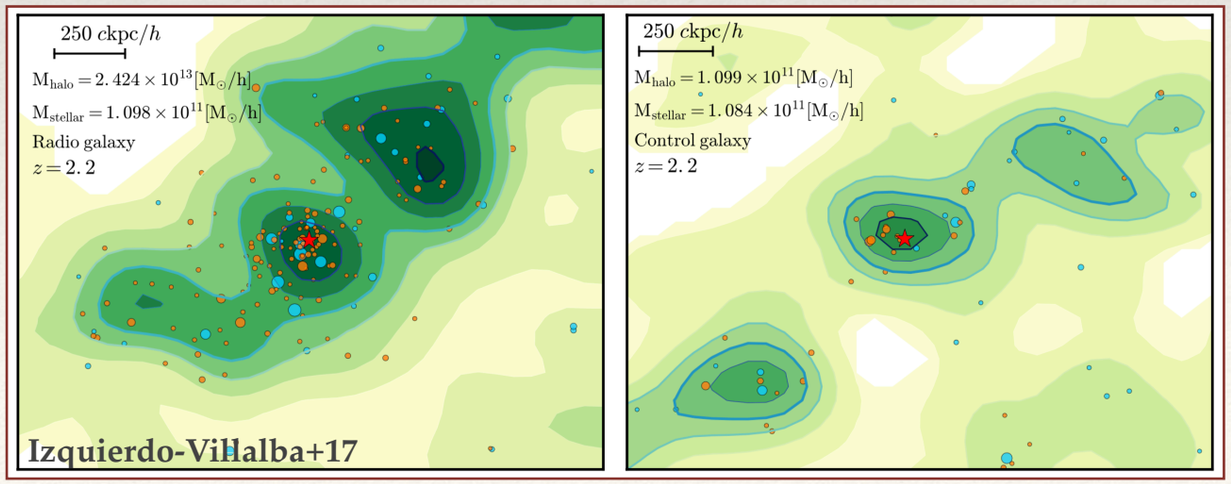
Hatch+14; Wylezalek+13+14



Simulations



- RL-galaxies sit in more massive DM halos than RQs with same stellar mass
- The impact of powerful AGN is reflected in the environment
- A higher fraction of passive galaxies around RL than RQ.



Questions That RAGERS Will Address

Radio-loud (RL) massive galaxies

- *What fraction of massive radio galaxies at high redshift sit in SMG overdensities?*
- *How do SMG-HzRG overdensities evolve with redshift? Strength, radial extent?*
- *Do SMG-HzRG overdensities depend on the intrinsic properties of the central radio galaxy?*

- The effect of powerful AGN feedback on the growth of protoclusters
- Quenching of star formation and stellar mass buildup
- Jet-induced star formation
- The role of the IGM

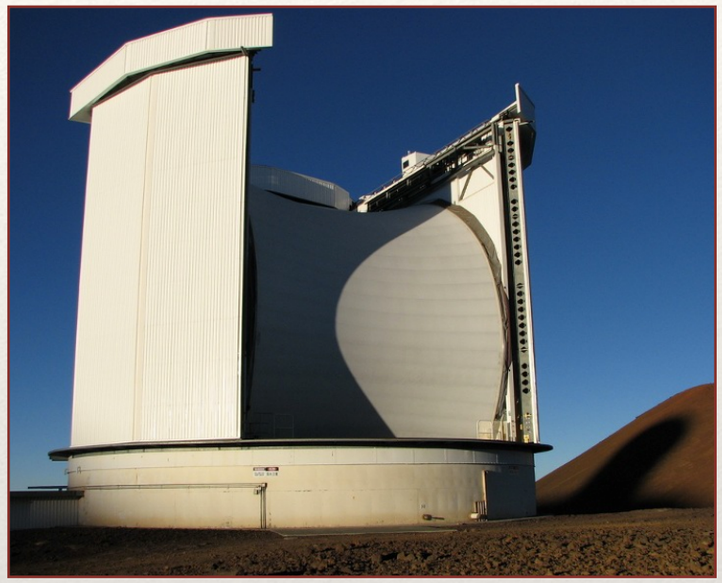
Radio-quiet (RQ) massive galaxies

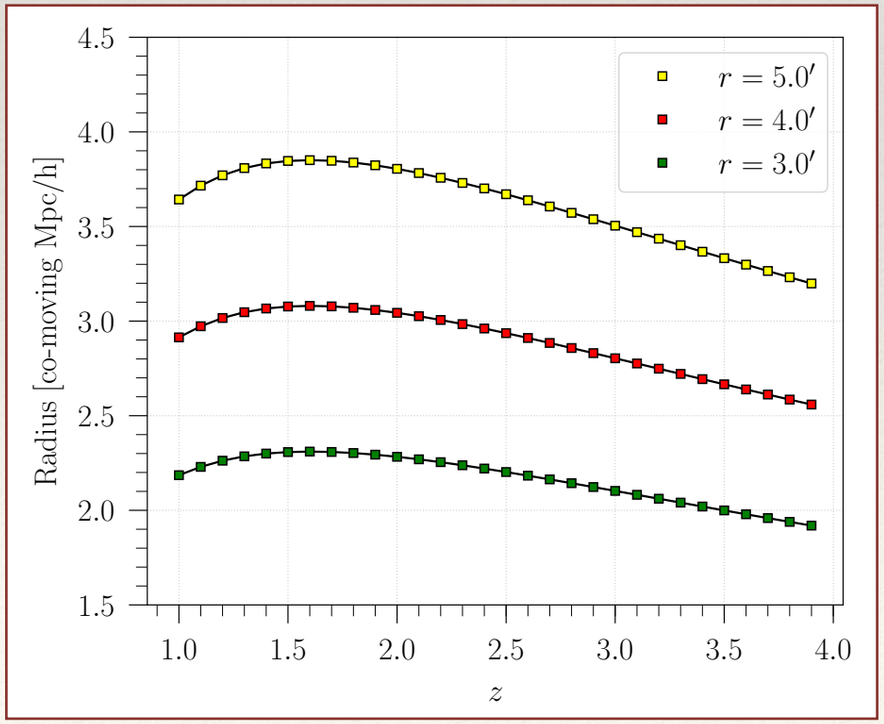
- *What fraction of massive radio-quiet galaxies at high redshift sit in SMG overdensities?*
- *How do SMG-RQ overdensities evolve with redshift? Strength, radial extent?*
- *Do SMG-RQ overdensities depend on the intrinsic properties of the central massive galaxy?*

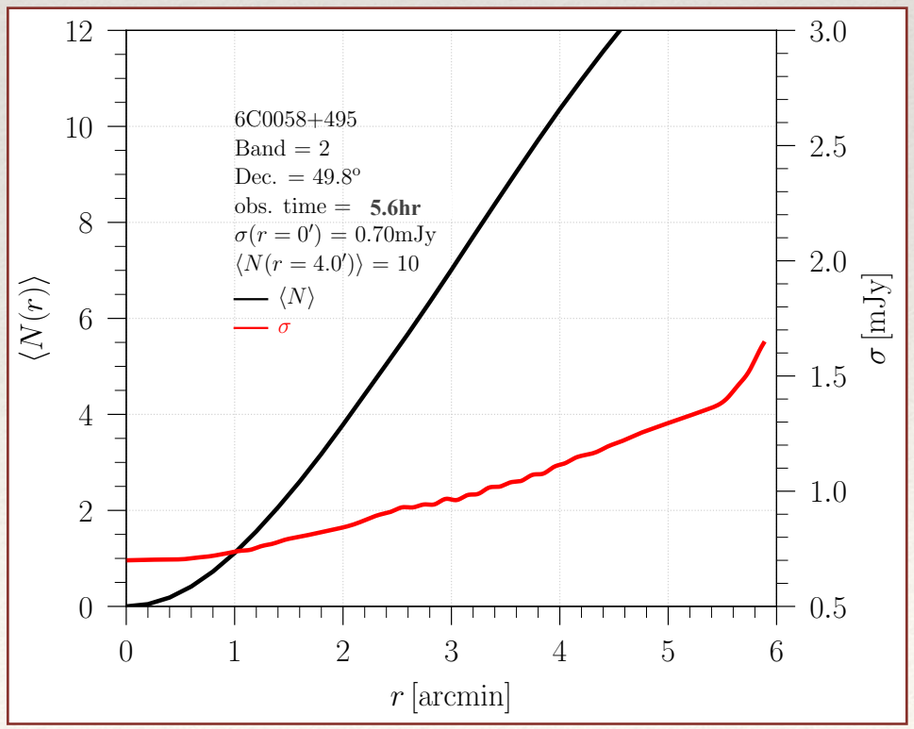
RAGERS in a Nutshell

A JCMT/SCUBA-2 Large Program to Map the Mpc-Scale Environments and SMG Overdensities Around 33 Radio-Loud and 33 Radio-Quiet Massive Galaxies at $1 < z < 3.5$

- Allocated 168hrs of SCUBA-2 time in Band 1 and 2
- Daisy Maps (~5′ FOV) down to r.m.s. ~0.7mJy
- Probe r~3Mpc (co-moving) regions
- Can expect >10 SMGs detected at SNR > 3.5 in each map







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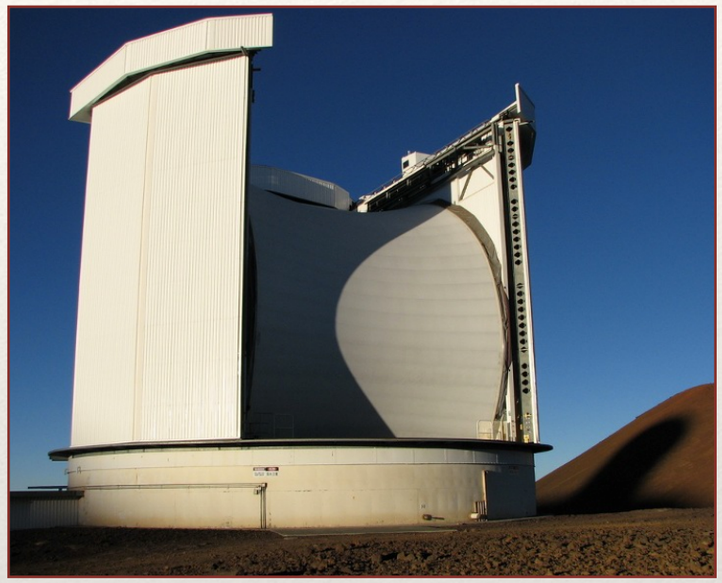
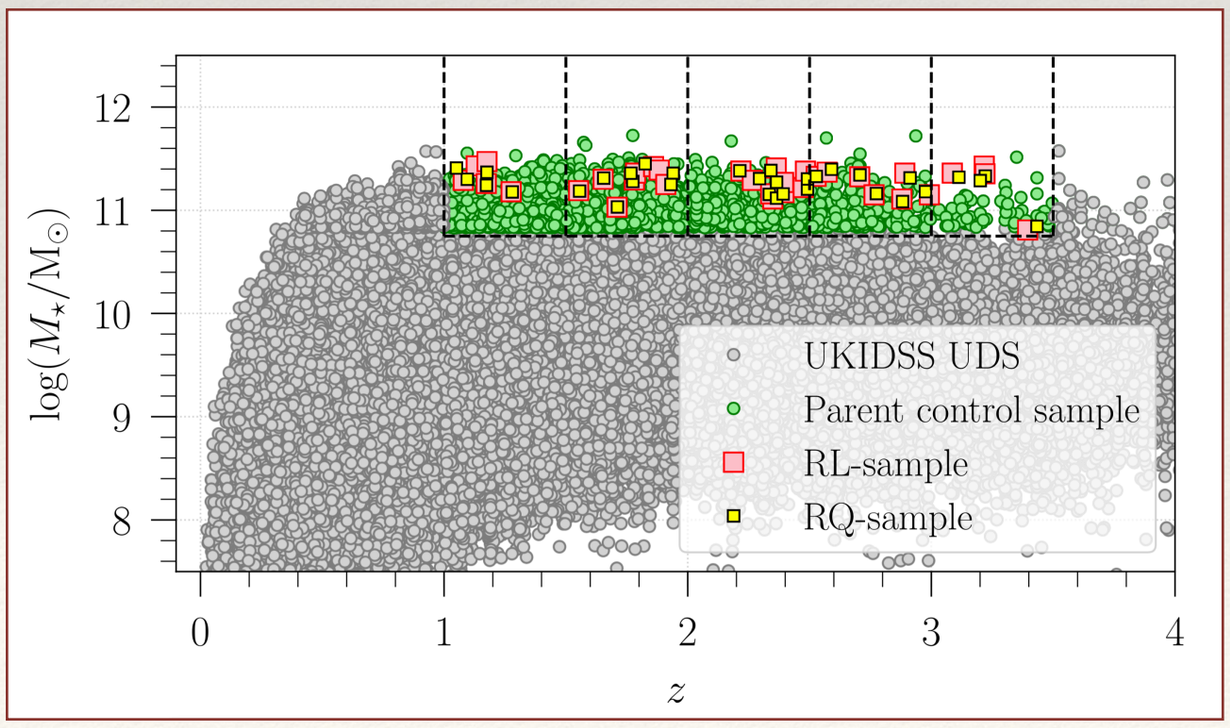
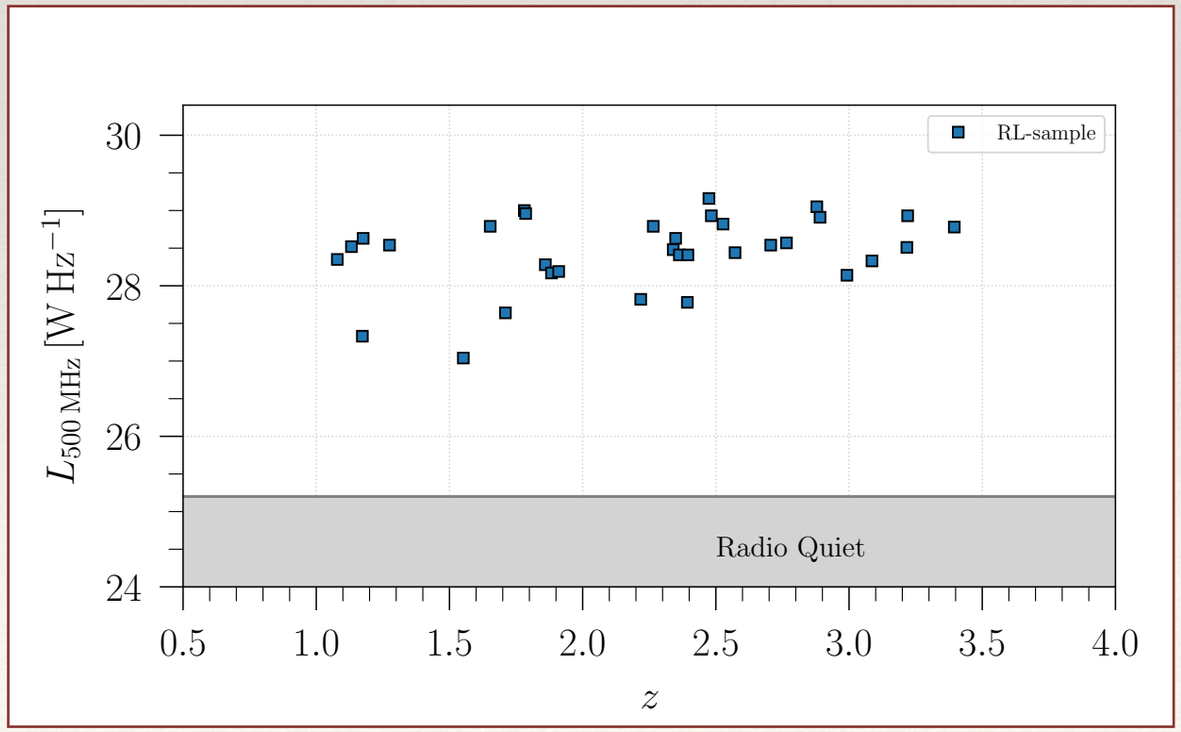
A JCMT/SCUBA-2 Large Program to Map the Mpc-Scale Environments and SMG Overdensities Around 33 Radio-Loud and 33 Radio-Quiet Massive Galaxies at $1 < z < 3.5$

- RL sample selected from the Herschel Radio Galaxy Evolution Project (Seymour+07+12; de Breuck+10)
- RQ sample selected from DR11 12-band matched catalogue from UKIDSS UDS Survey
- $\log(M_\star) = 10.7\text{-}11.5$ (RL and RQ samples matched)
- At least 4 sources in each z-bin







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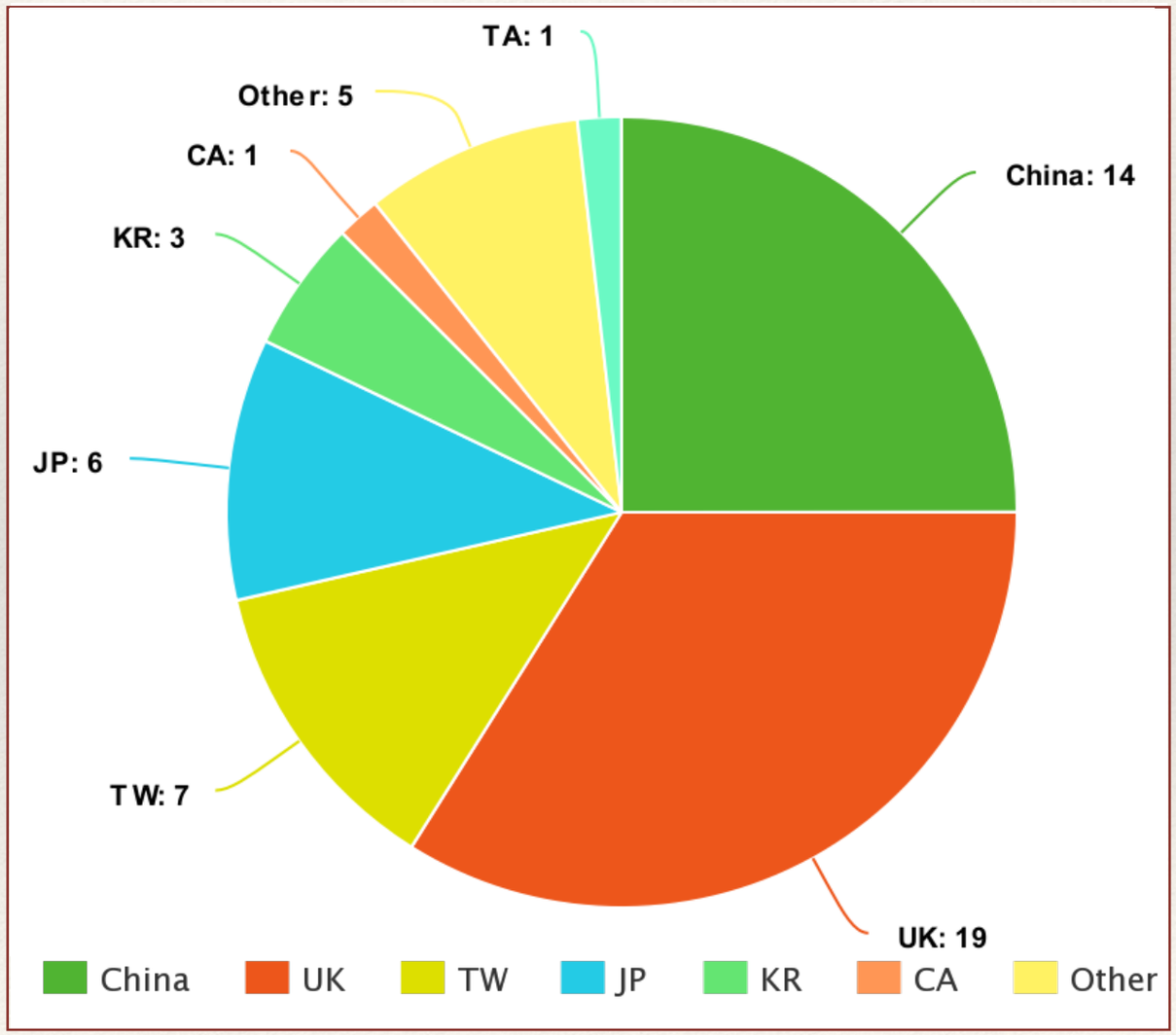
A JCMT/SCUBA-2 Large Program to Map the Mpc-Scale Environments and SMG Overdensities Around 33 Radio-Loud and 33 Radio-Quiet Massive Galaxies at $1 < z < 3.5$

- 56 astronomers from primarily EAO countries, UK, and CA

- Regional coordinators:
  - Thomas Greve, UCL, UK
  - Chian-Chou Chen, ASIAA, Taiwan
  - Zhiyu Zhang, Nanjing University, China
  - Tadayuki Kodama, Tohoku University, Japan
  - Hyunjin Shim, Kyungpook National University, Korea
  - Scott Chapman, Dalhousie University, Canada
  - Wiphu Rujopakarn, Chulalongkorn University, Thailand

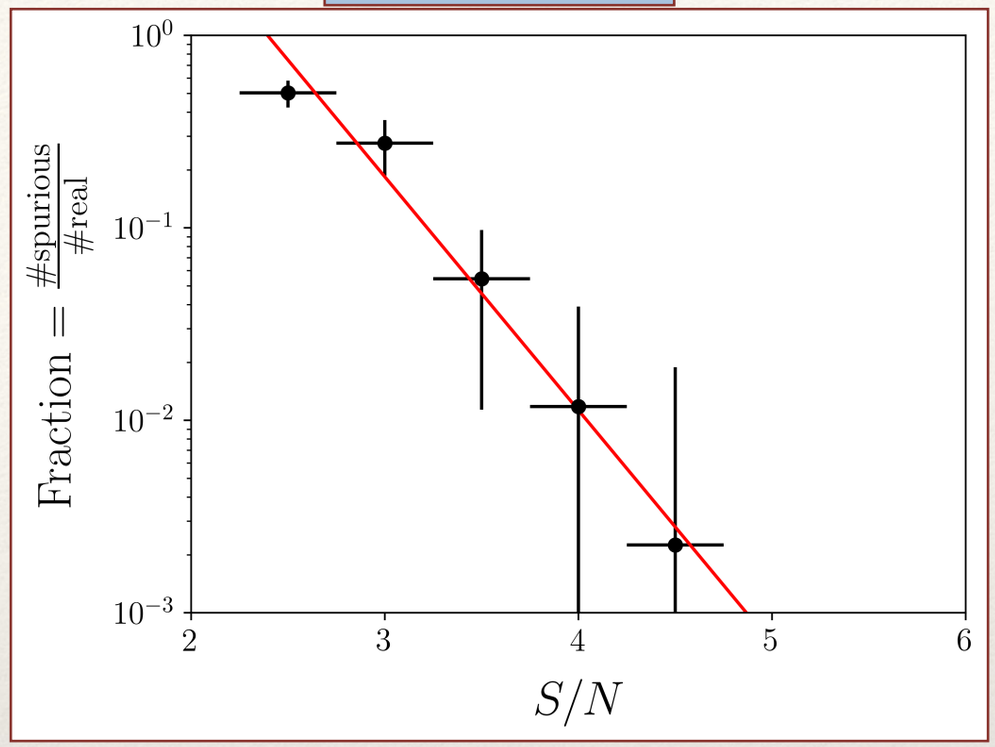


https://www.eaobservatory.org/jcmt/science/large-programs/ragers/

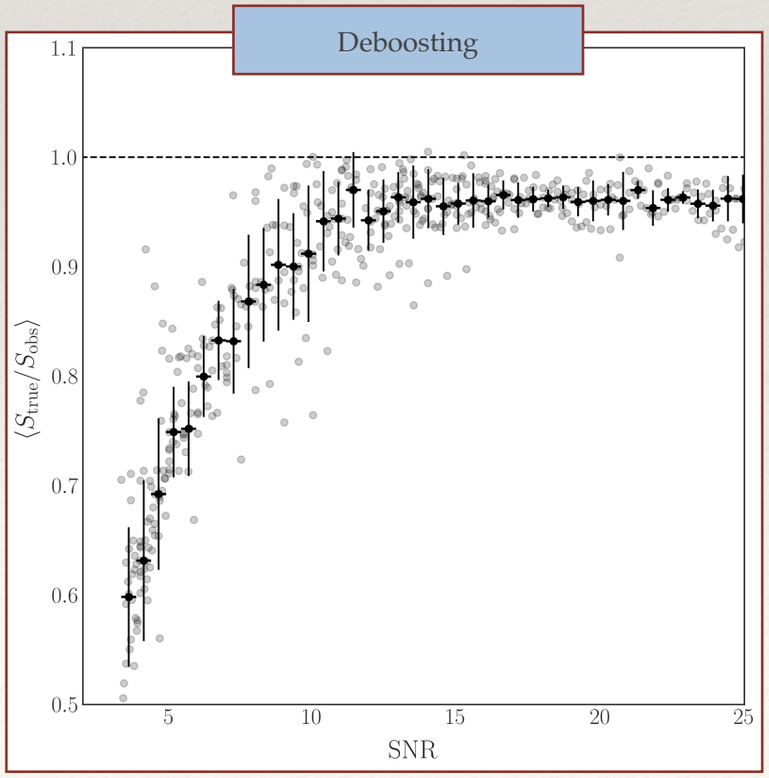
Current Status

- Survey is 56% complete
- 14 fields completed.
- DR Pipeline
- Deboosting and completeness correction

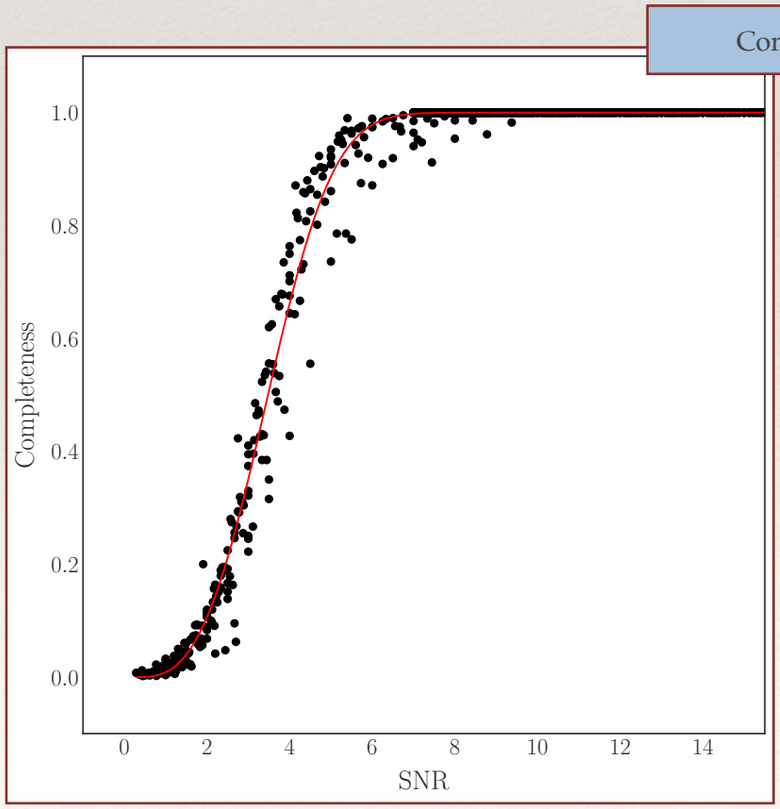
Spurious sources

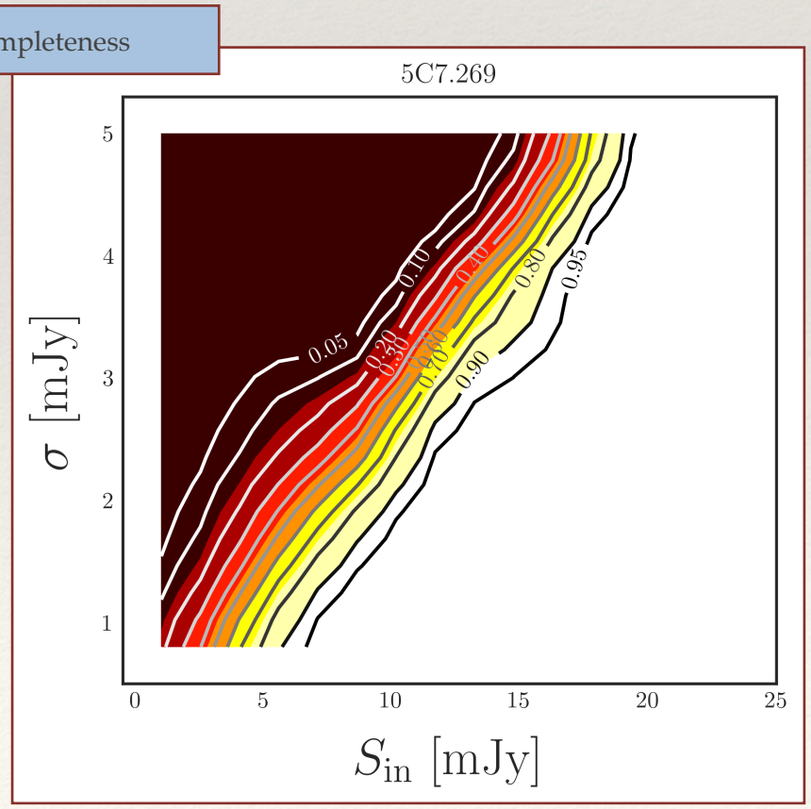


Deboosting



Completeness

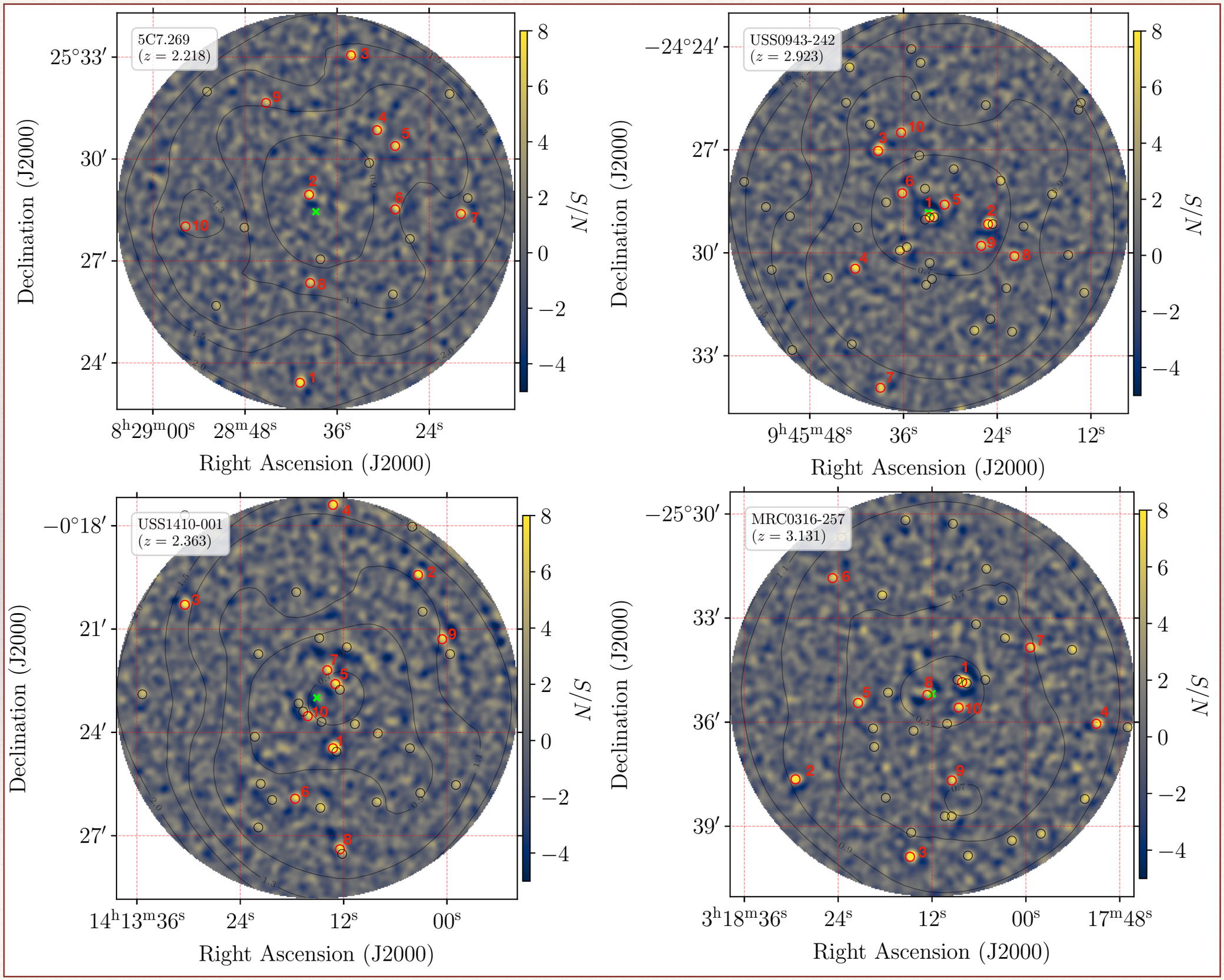




Current Status

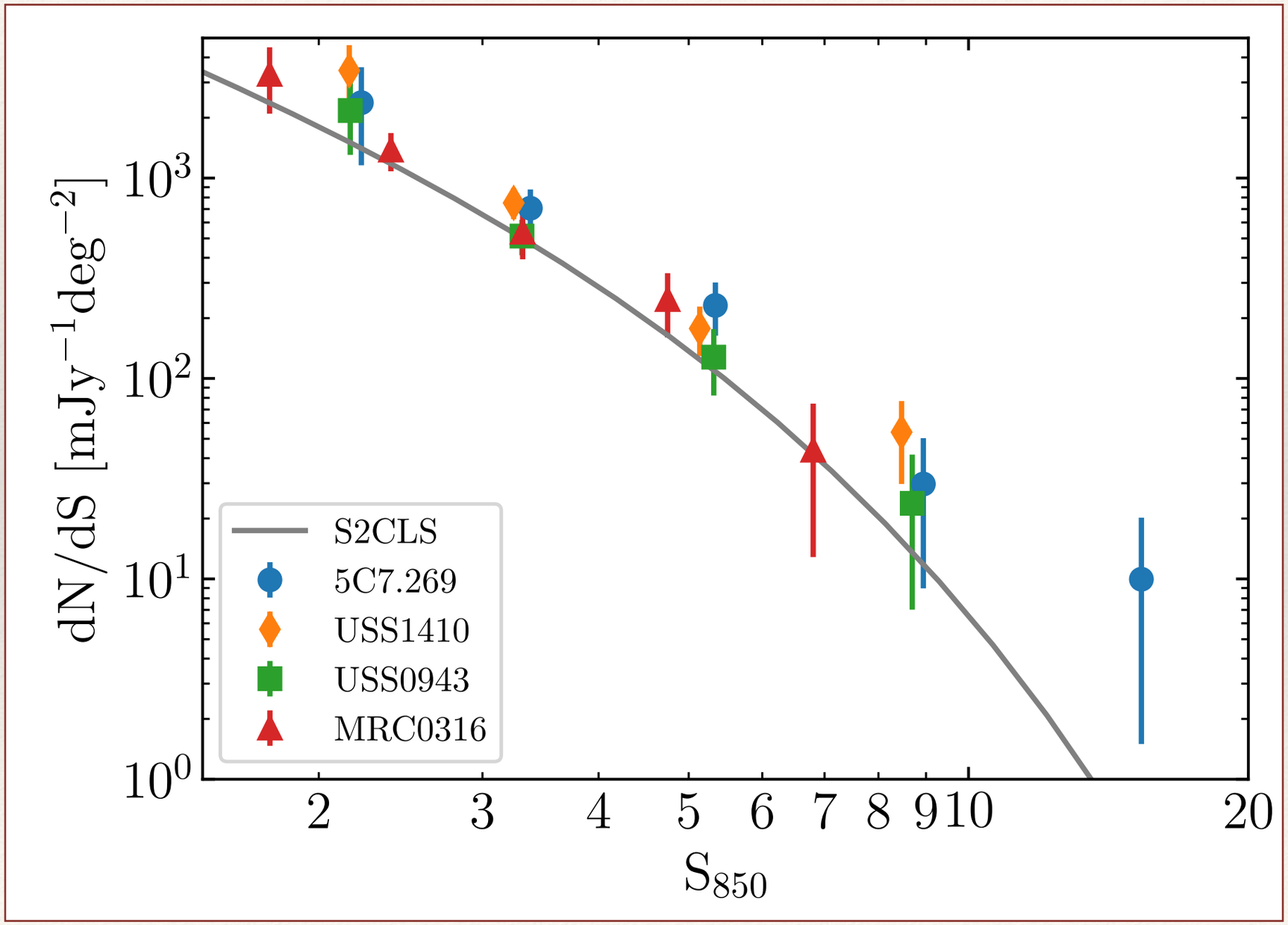
Example Fields

Work in progress



Current Status

- Most of our fields are mildy overense (2-4x) at the bright end



Work in progress

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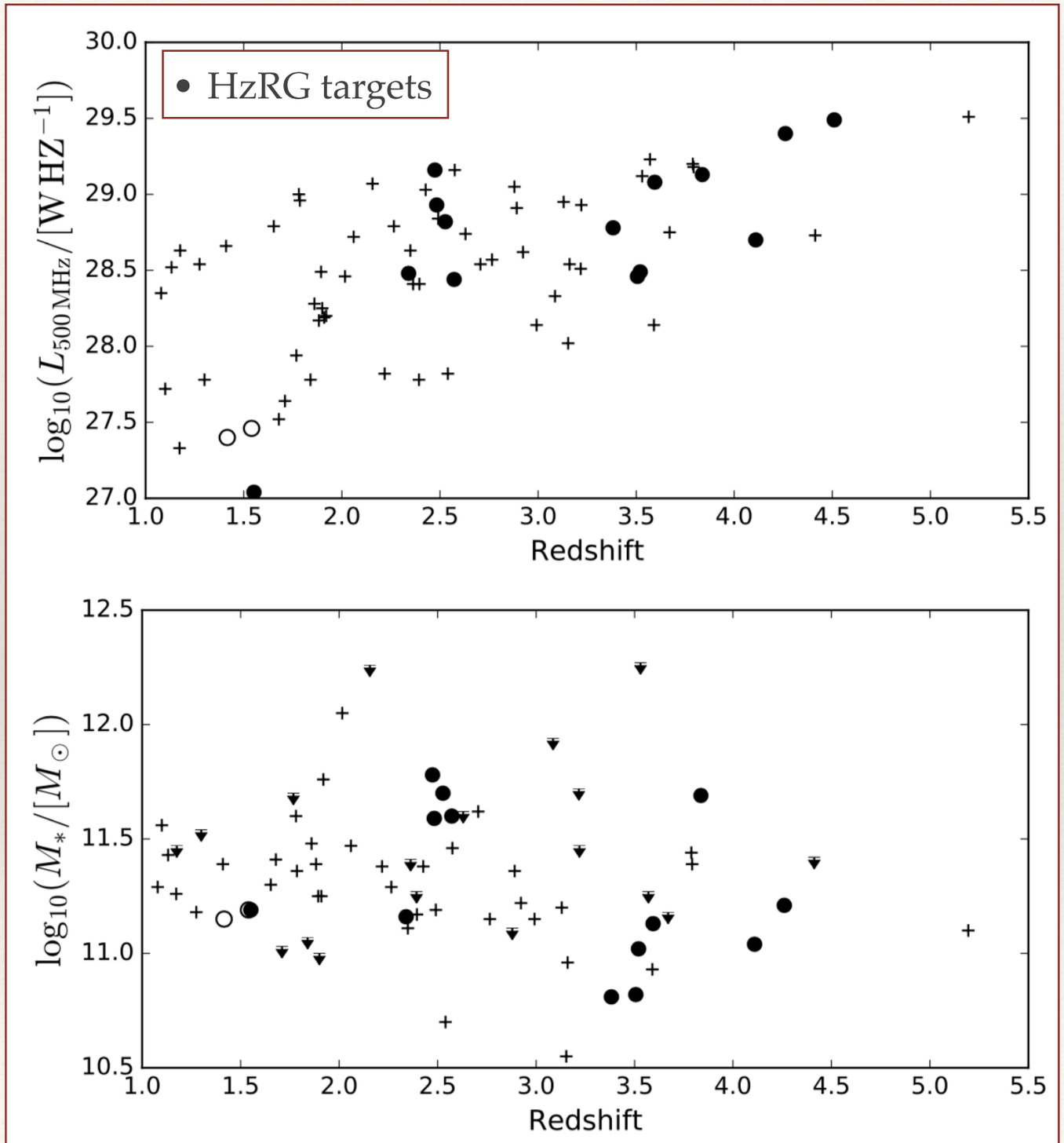
Sample Selection

- Mining the SCUBA-2 archive
- 14 HzRGs at 1.5 < z < 4.5 targetted with SCUBA-2
- Pong900 maps of 14 HzRGs (FOV 12′). Rms noise 2mJy/beam
- Selected from the Herschel Radio Galaxy Evolution Project (PI: Seymour). Spitzer coverage (De Breuck) + LABOCA or AzTEC (in some cases)

Target	Redshift	RA	Dec	$\log_{10}(L_{500\,\mathrm{MHz}})$[a]
3C 257	2.47	$11^{\mathrm{h}}23^{\mathrm{m}}09^{\mathrm{s}}.2$	$+05°30'19''$	29.16
4C +23.56	2.48	$21^{\mathrm{h}}07^{\mathrm{m}}14^{\mathrm{s}}.8$	$+23°31'45''$	28.93
B2 0902+34	3.38	$09^{\mathrm{h}}05^{\mathrm{m}}30^{\mathrm{s}}.1$	$+34°07'57''$	28.78
MG J214405+1929	3.59	$21^{\mathrm{h}}44^{\mathrm{m}}07^{\mathrm{s}}.0$	$+19°29'15''$	29.08
TN J0121+1320	3.52	$01^{\mathrm{h}}21^{\mathrm{m}}42^{\mathrm{s}}.7$	$+13°20'58''$	28.49
TN J0205+2242	3.51	$02^{\mathrm{h}}05^{\mathrm{m}}10^{\mathrm{s}}.7$	$+22°42'51''$	28.46
TN J2007−1316	3.84	$20^{\mathrm{h}}07^{\mathrm{m}}53^{\mathrm{s}}.2$	$-13°16'45''$	29.13
TXS 0211−122	2.34	$02^{\mathrm{h}}14^{\mathrm{m}}17^{\mathrm{s}}.4$	$-11°58'46''$	28.48
USS 0828+193	2.57	$08^{\mathrm{h}}30^{\mathrm{m}}53^{\mathrm{s}}.4$	$+19°13'16''$	28.44
USS 1558−003	2.53	$16^{\mathrm{h}}01^{\mathrm{m}}17^{\mathrm{s}}.3$	$-00°28'47''$	28.82
LBDS 53W091	1.55	$17^{\mathrm{h}}22^{\mathrm{m}}32^{\mathrm{s}}.7$	$+50°06'02''$	27.04
TN J1338−1942	4.11	$13^{\mathrm{h}}38^{\mathrm{m}}26^{\mathrm{s}}.1$	$-19°42'31''$	28.70
8C 1435+635	4.26	$14^{\mathrm{h}}36^{\mathrm{m}}37^{\mathrm{s}}.3$	$+63°19'13''$	29.40
RC J0311+0507	4.51	$03^{\mathrm{h}}11^{\mathrm{m}}48^{\mathrm{s}}.0$	$+05°08'03''$	29.49



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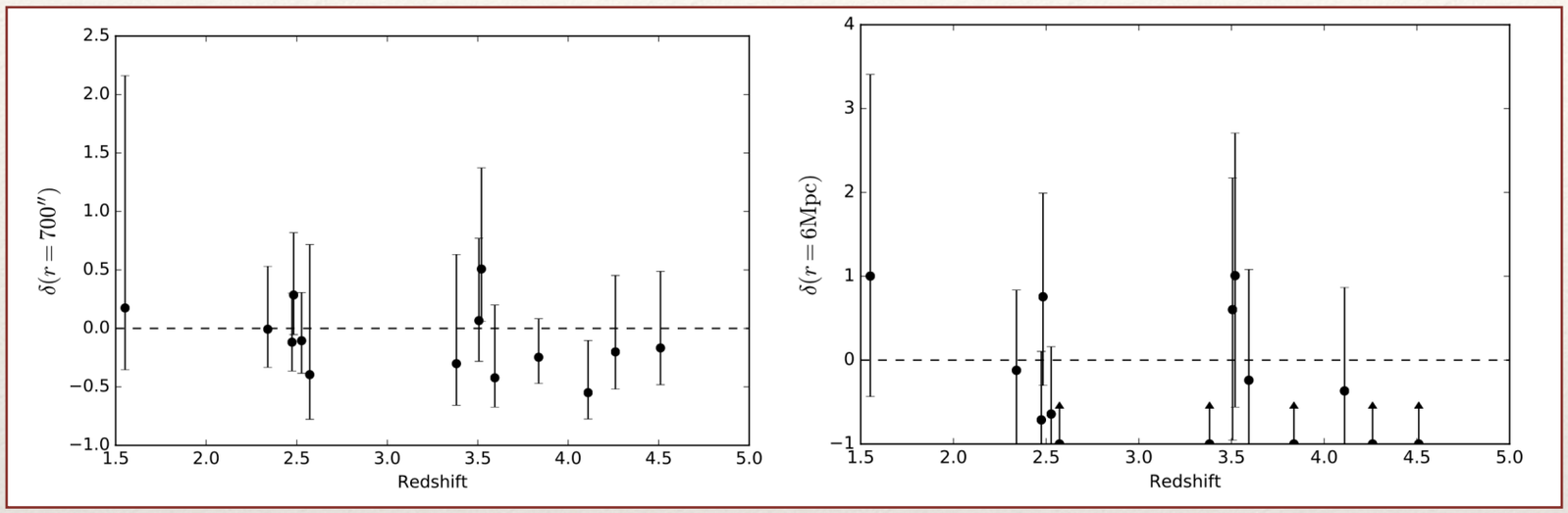
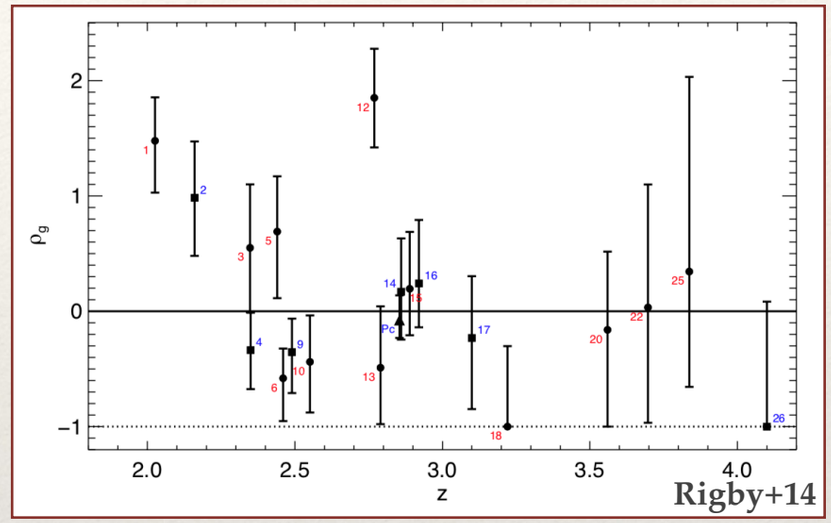
SMG Overdensity Evolution with Redshift

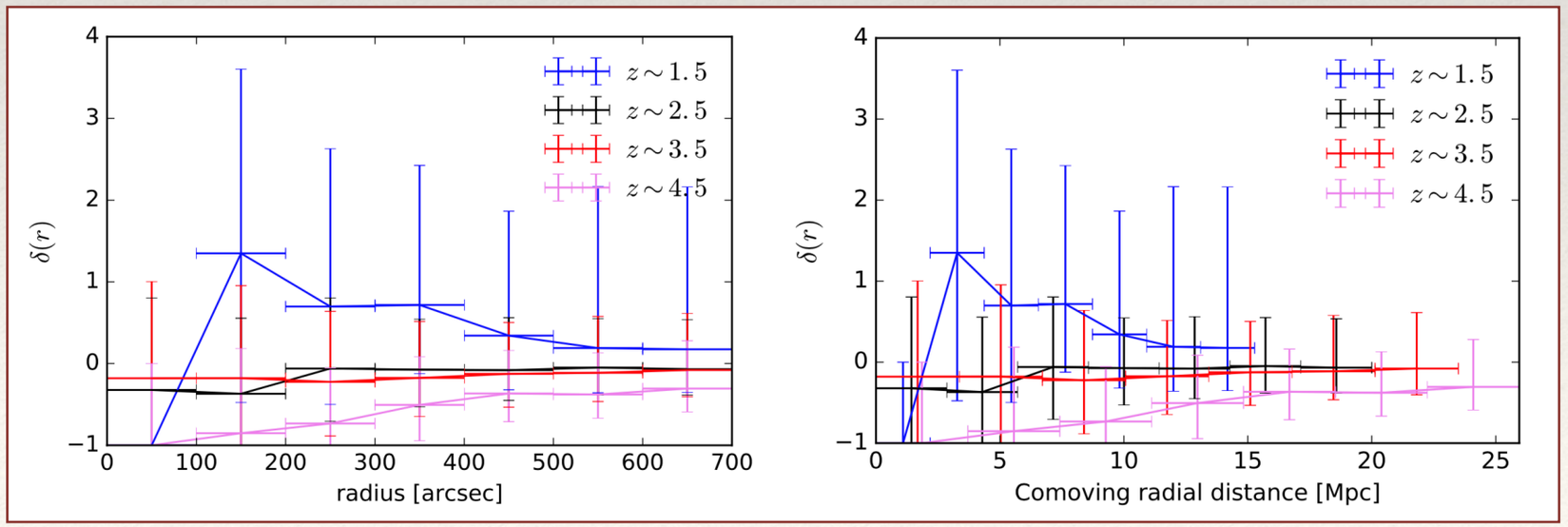
- Weak trend of decreasing total SMG overdensities with redshift - **but consistent with no evolution**



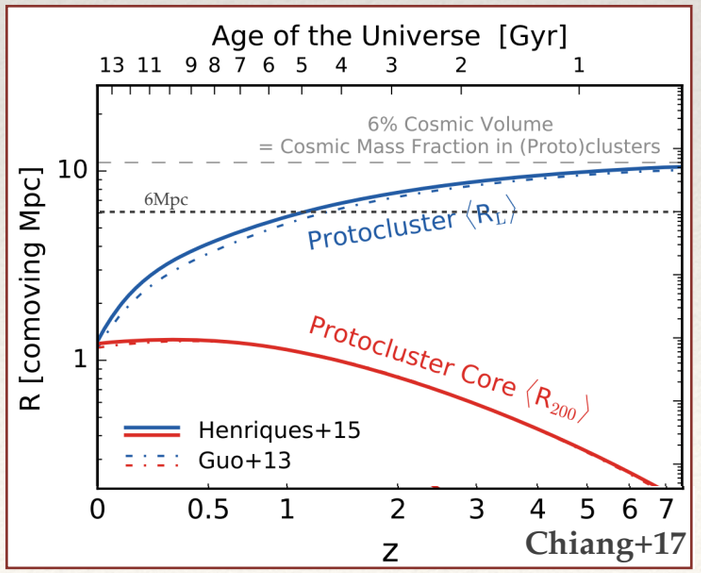
- Qualitatively consistent with Rigby+14 results



- Tentative trend of evolution with redshift of the SMG overdensity profile



- Is such a trend expected?



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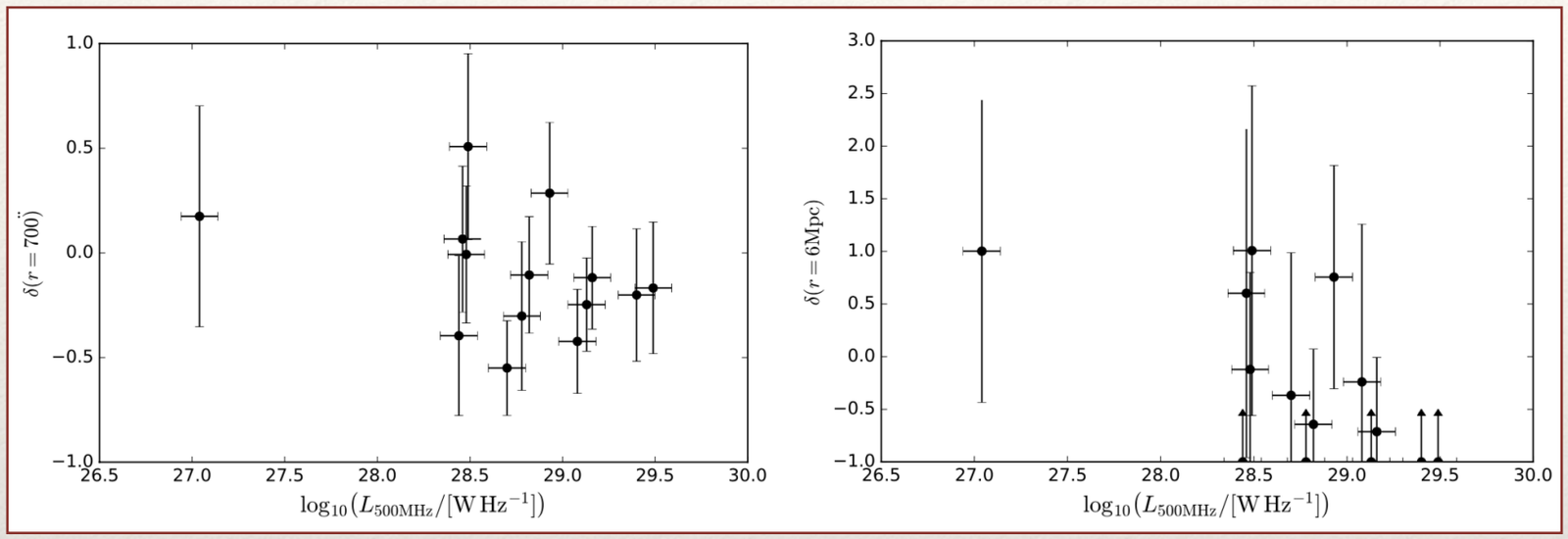
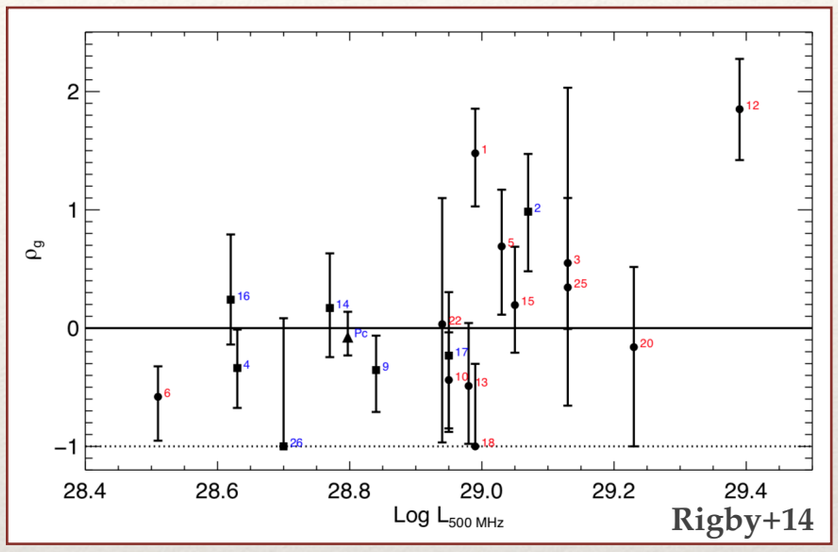
SMG Overdensity and Intrinsic RG Properties

- No correlation between SMG overdensity and RG radio power

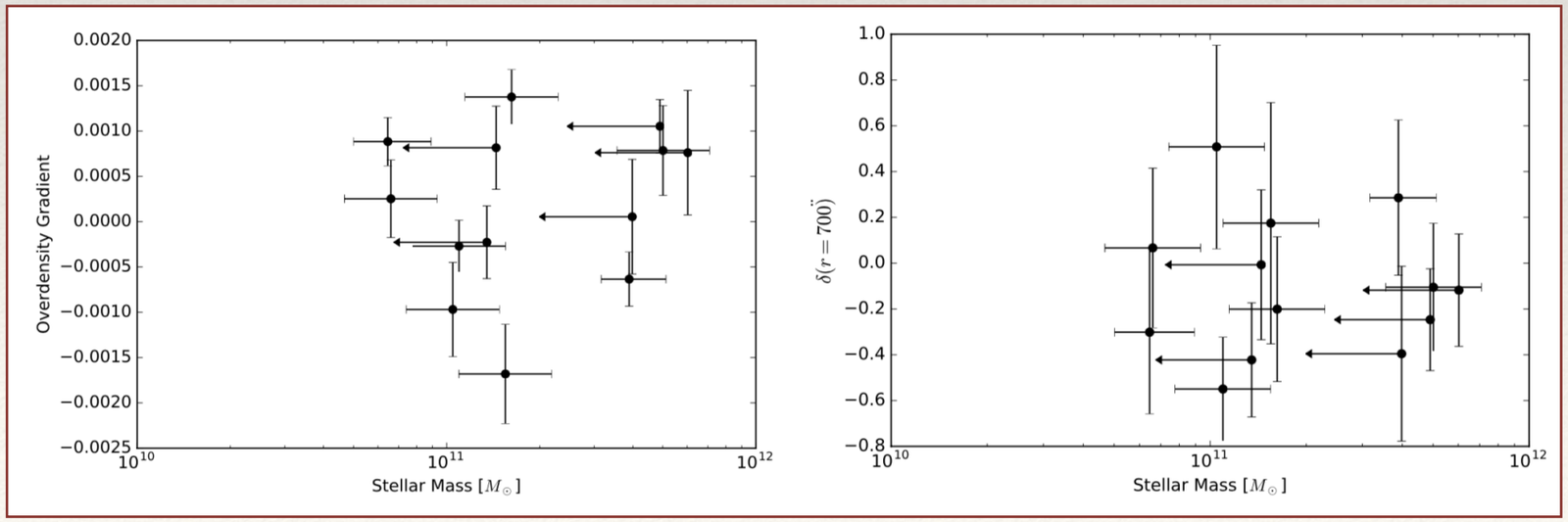


- Weak trend with radio power (Rigby+14; Galametz+12)

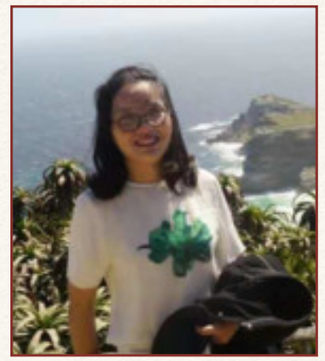


cf. Miley & De Breuck+08; Falder+10

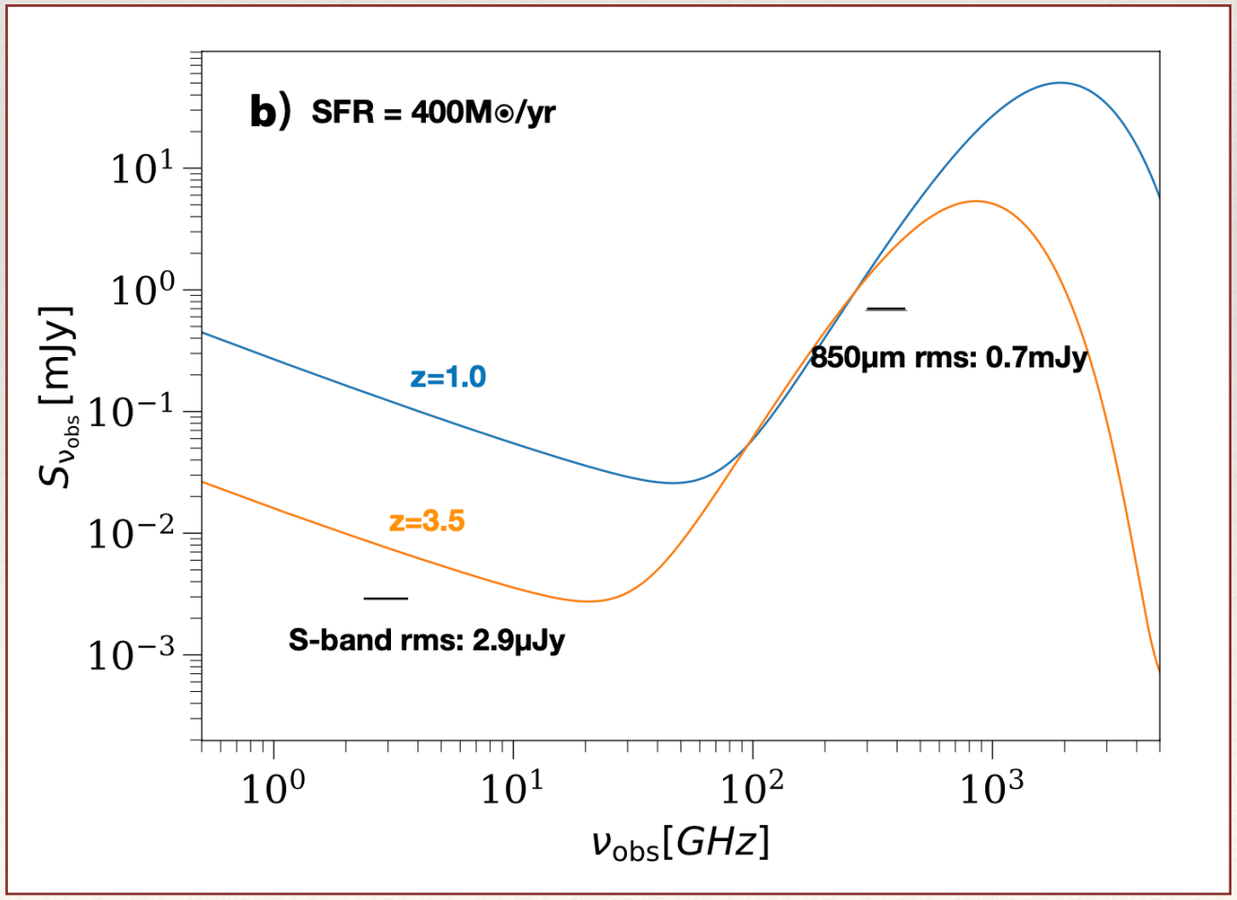
- No correlation between SMG overdensity and RG stellar mass

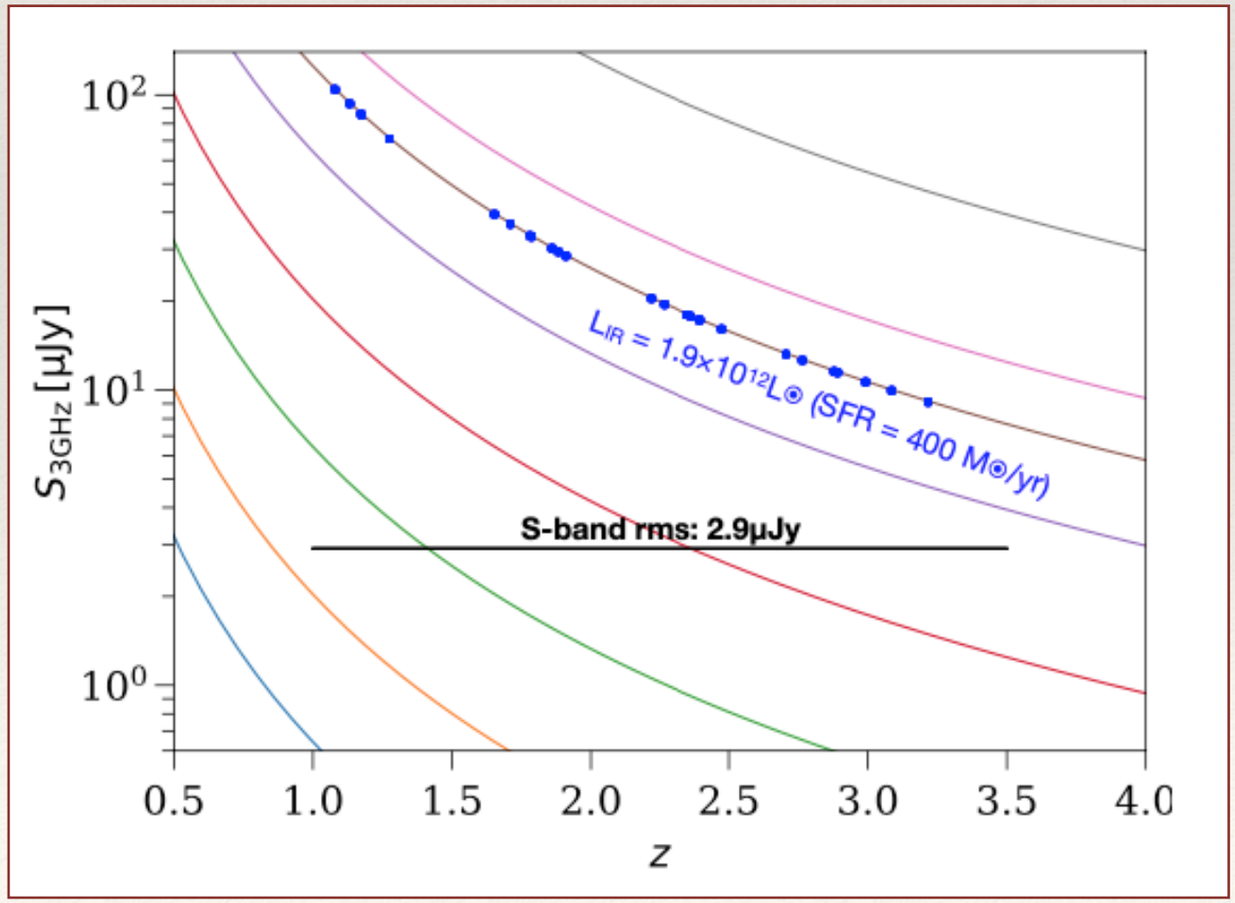


Radio Followup: VLA-RAGERS



- Completed 94hr VLA program for S-band followup of RAGERS targets (**VLA/20B-375**)
- Lead by PhD student **Yuanqi Liu, PKU**
- All RAGERS Fields observed and imaged at 3GHz





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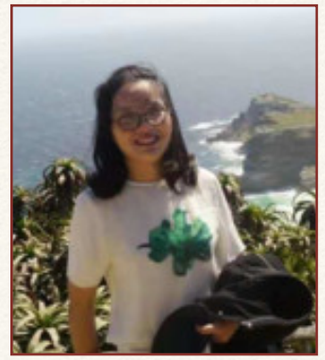
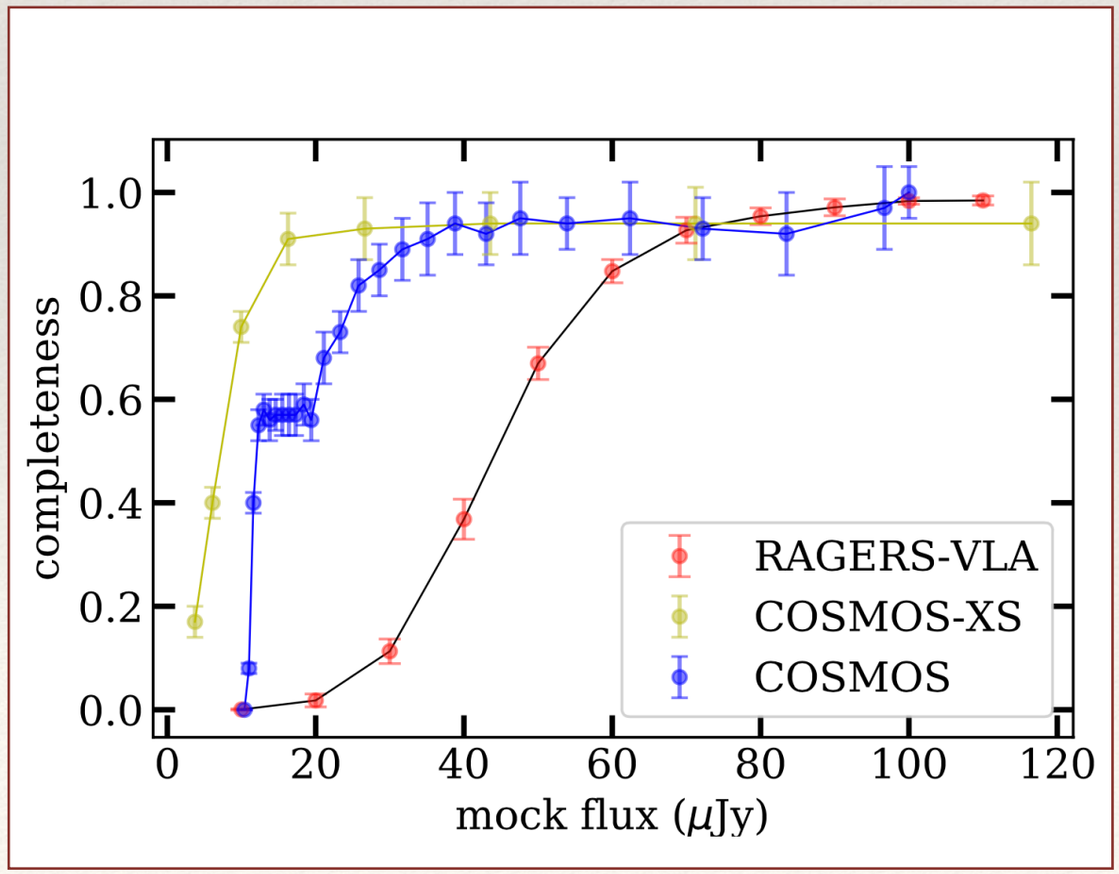
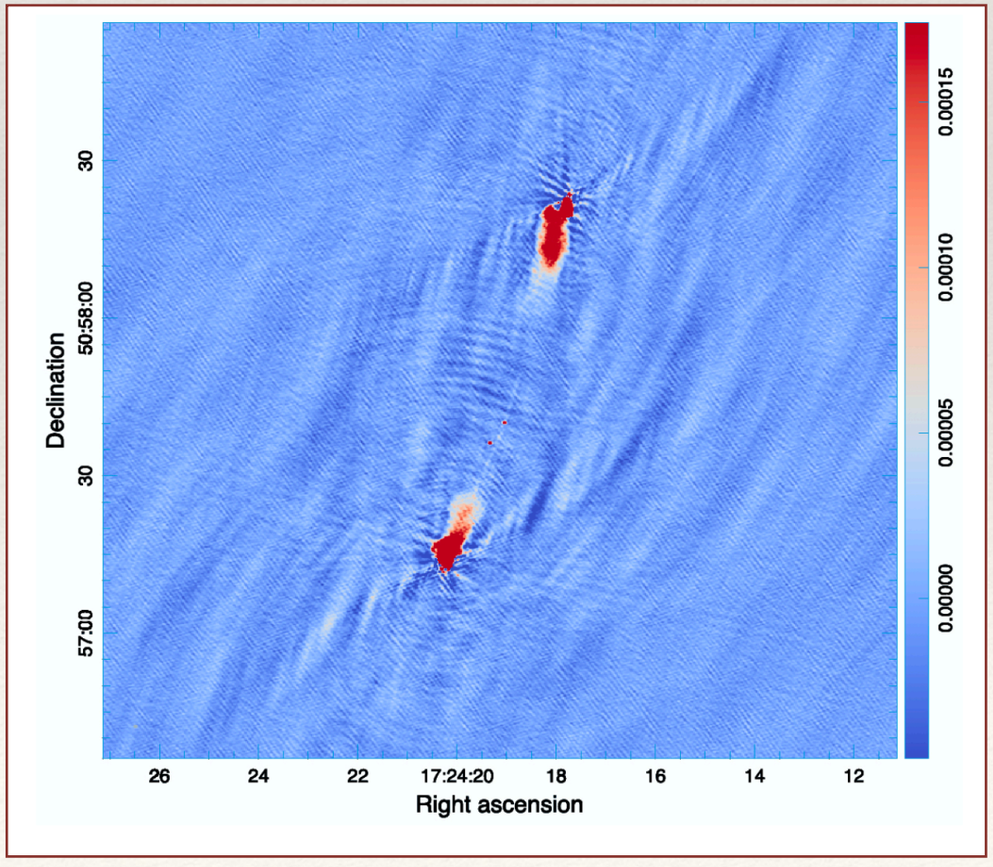
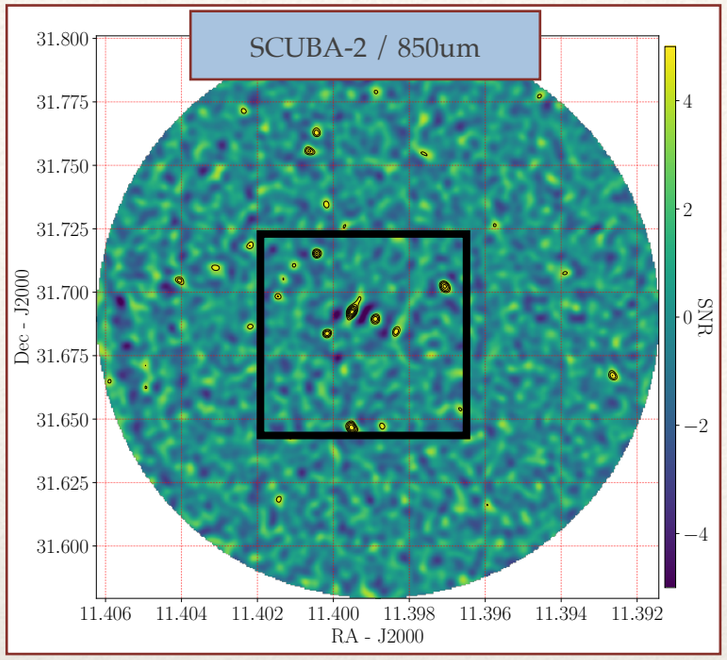


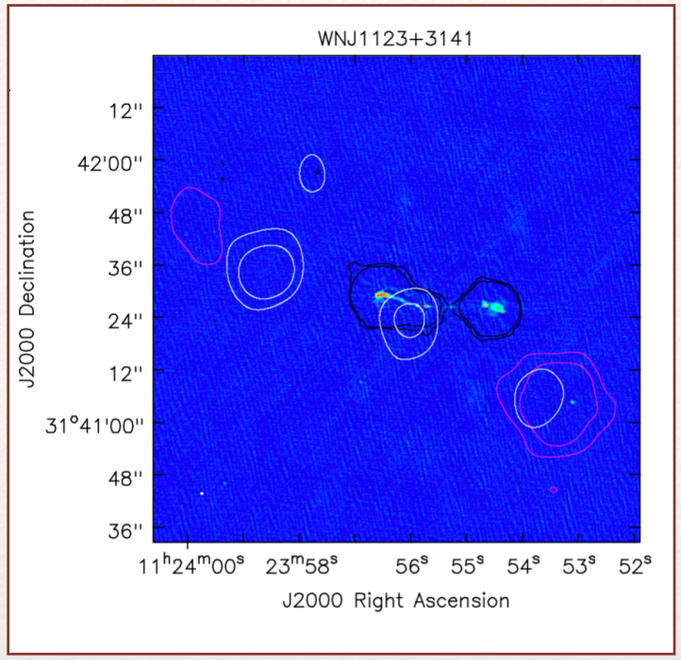
- Completed 94hr VLA program for S-band followup of RAGERS targets (**VLA/20B-375**)
- Lead by PhD student **Yuanqi Liu, PKU**
- All RAGERS Fields observed and imaged at 3GHz
- Targeted rms 2.9uJy, actual rms ~10uJy due to dynamical range issues from cental RG
- Source extraction using Pybdsf





Radio Followup: WNJ1123+3141 (z=3.22)

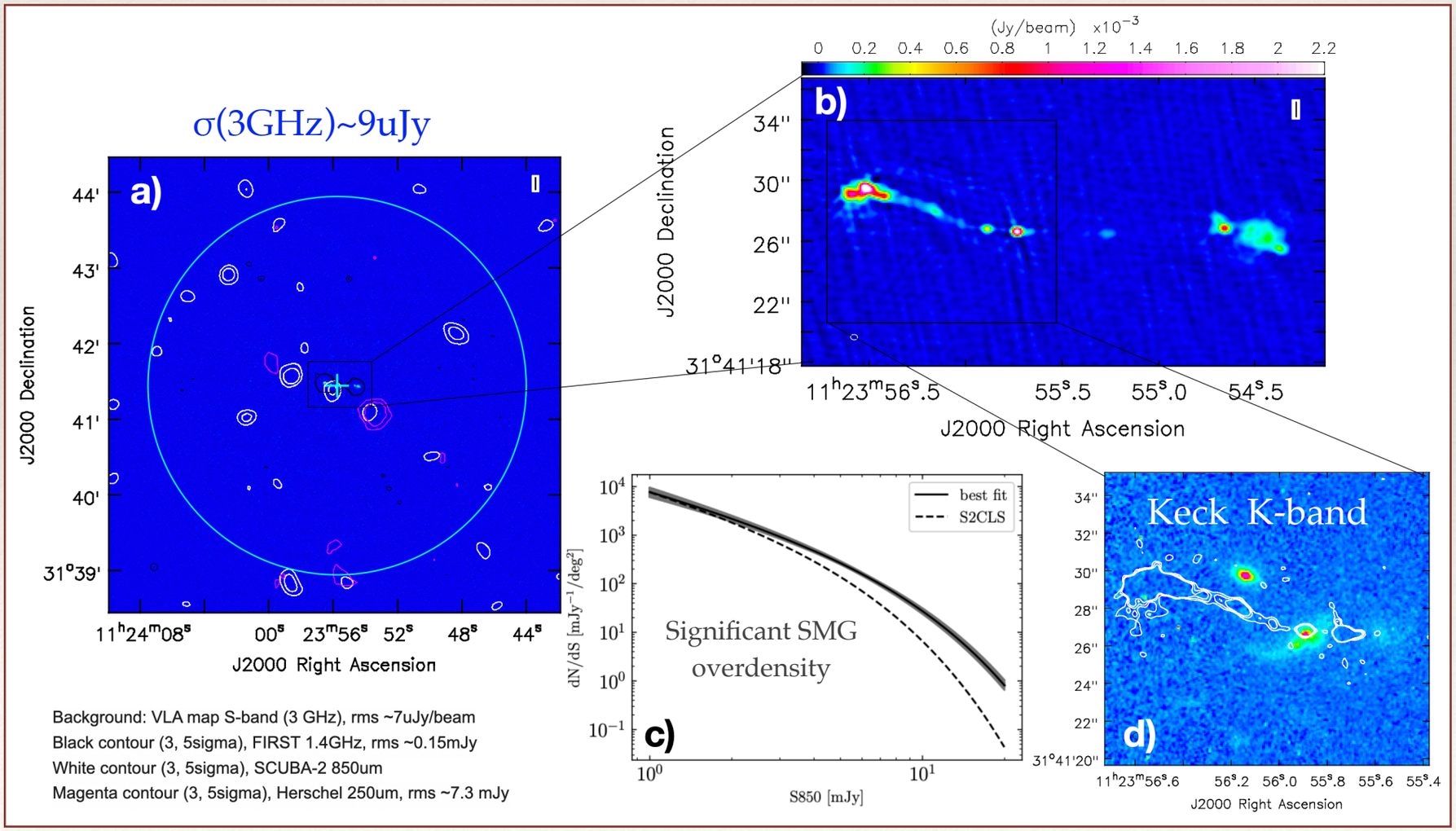




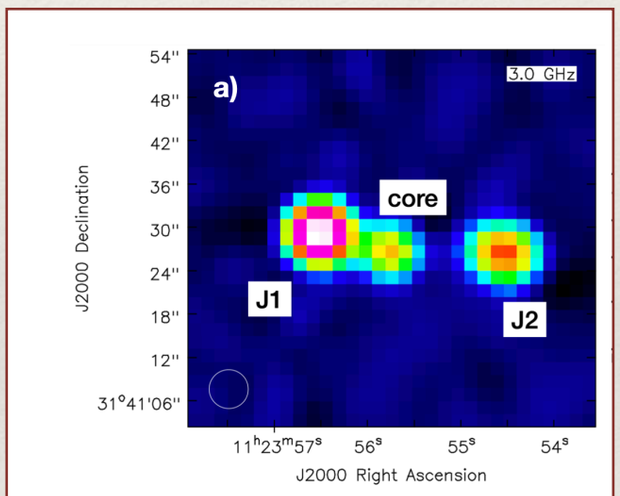
- Jet-induced star-formation?
- Radio galaxy - ICM connection?
- Mapping of spectral index of radio lobes

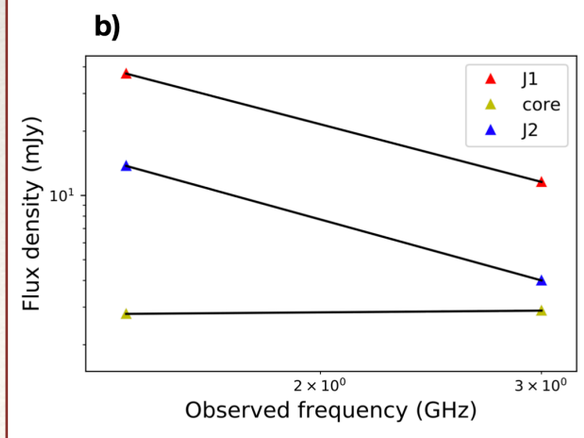
Liu in prep.

σ(3GHz)~9uJy



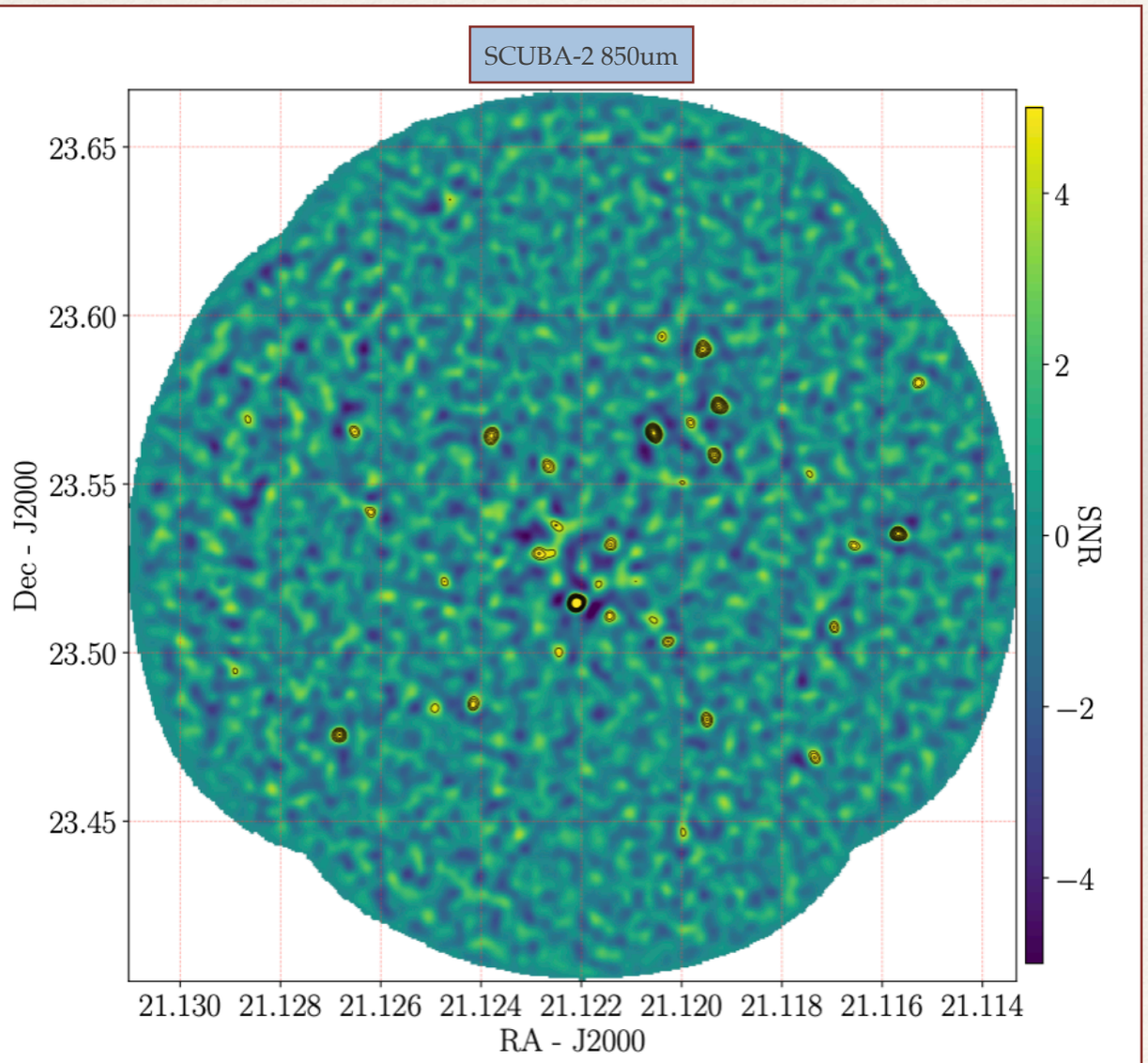
Background: VLA map S-band (3 GHz), rms ~7uJy/beam
Black contour (3, 5sigma), FIRST 1.4GHz, rms ~0.15mJy
White contour (3, 5sigma), SCUBA-2 850um
Magenta contour (3, 5sigma), Herschel 250um, rms ~7.3 mJy

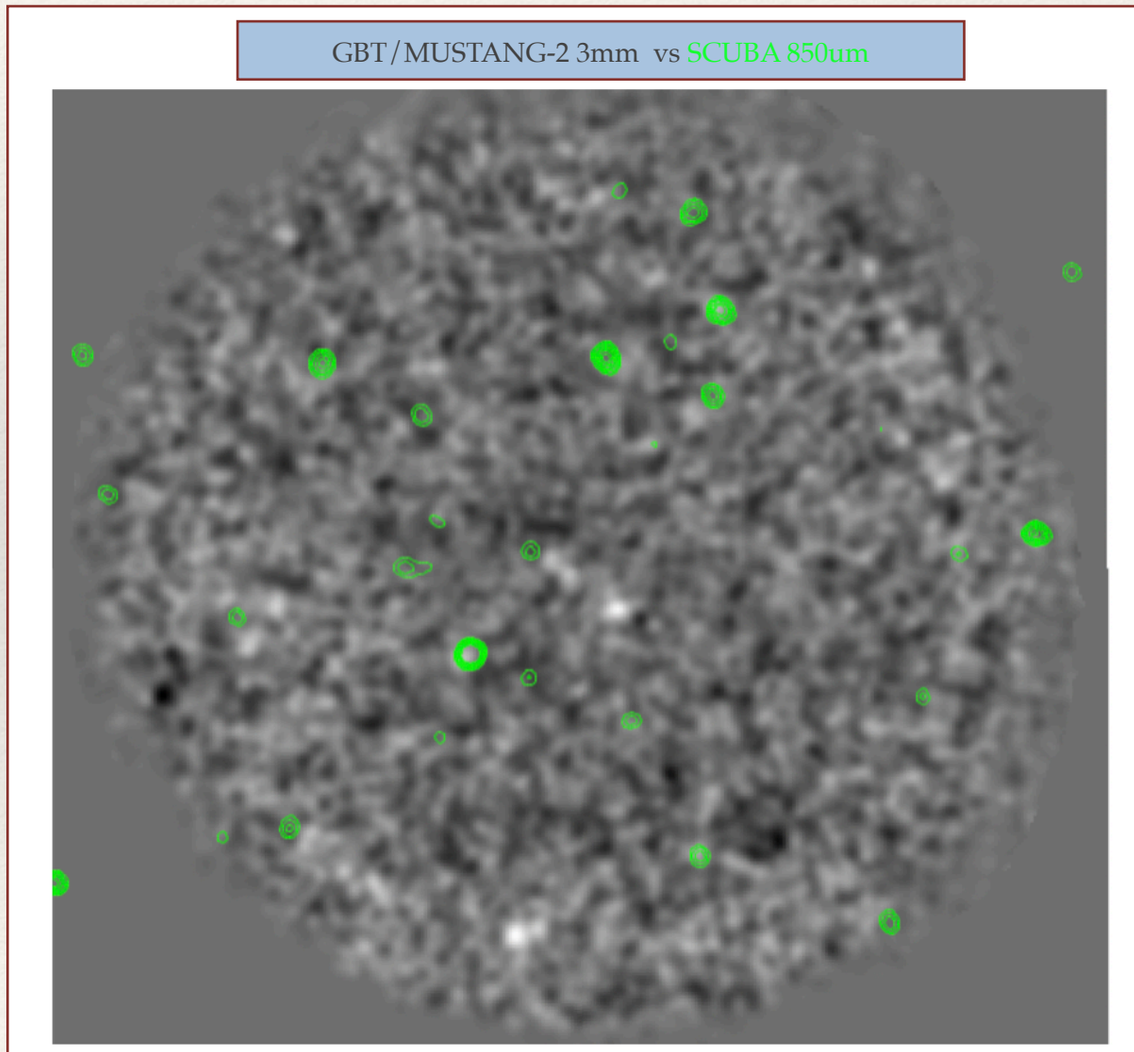




Radio Followup: 4C23.56 (z=2.48)

- Completed 10hr GBT MUSTANG-2 3mm program mapping 4C23.56 (**GBT-21A-299**)
- Lead by PhD student **Dazhi Zhou, DAWN**
- Targeted rms ~16uJy





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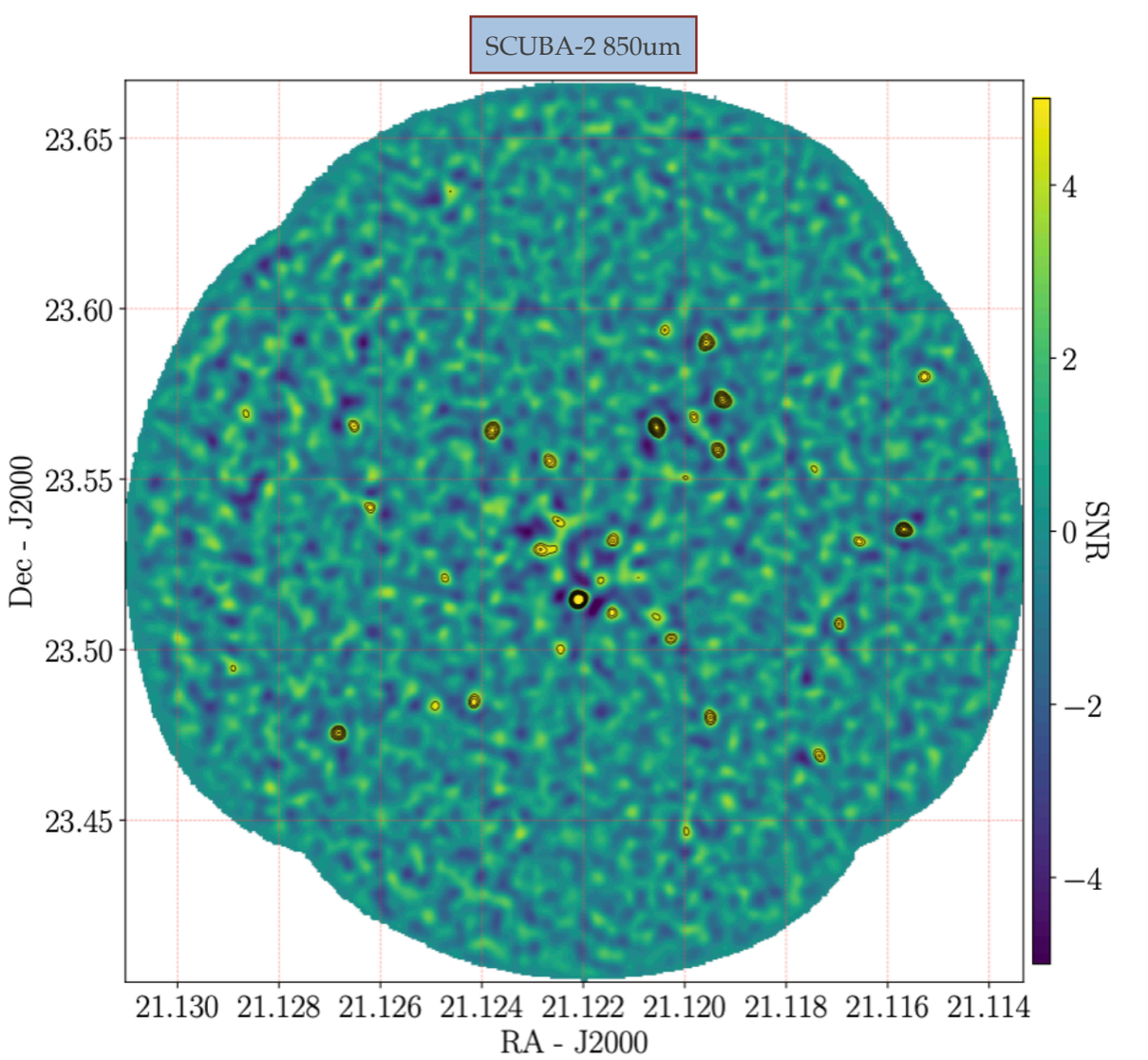
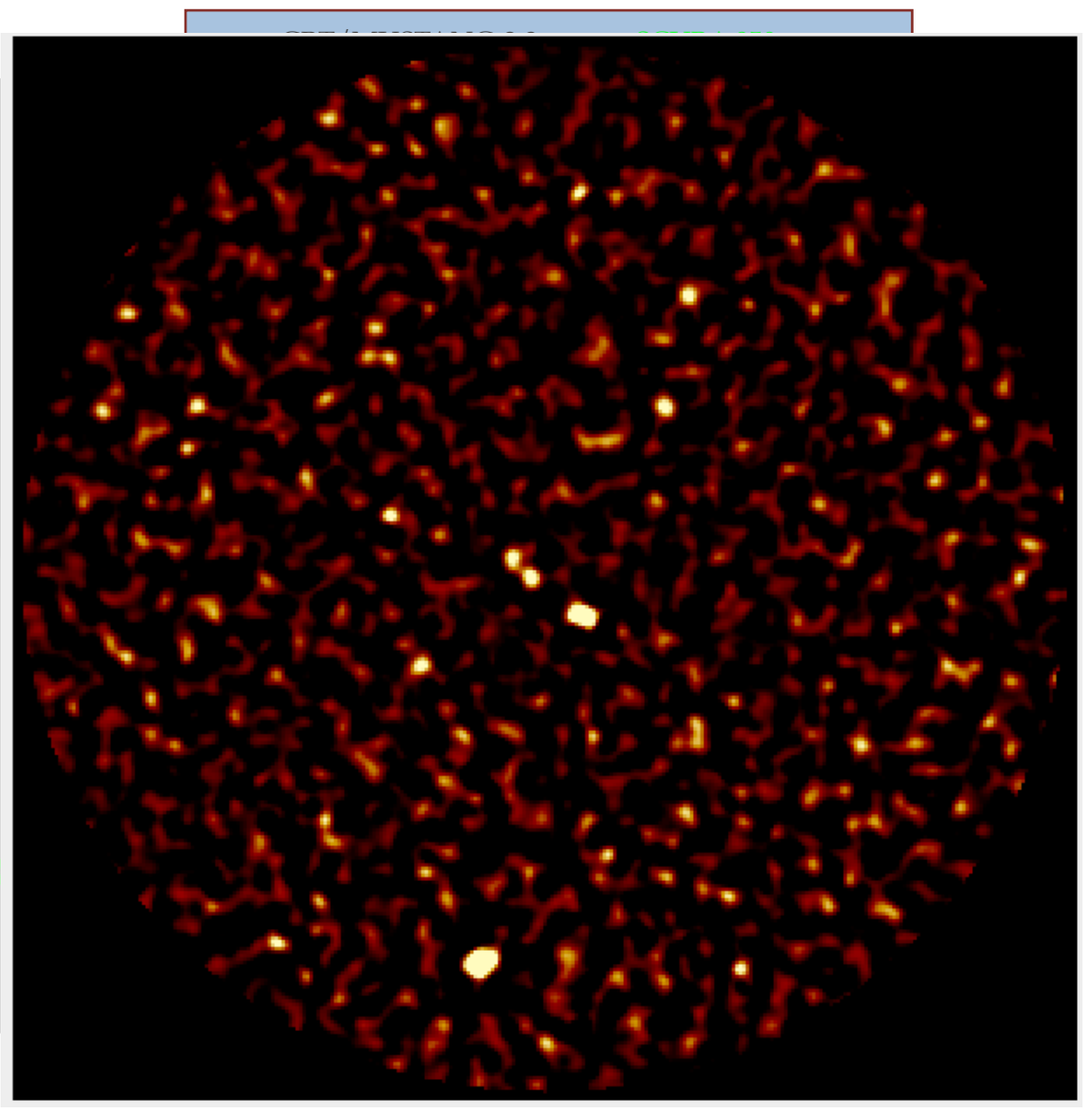
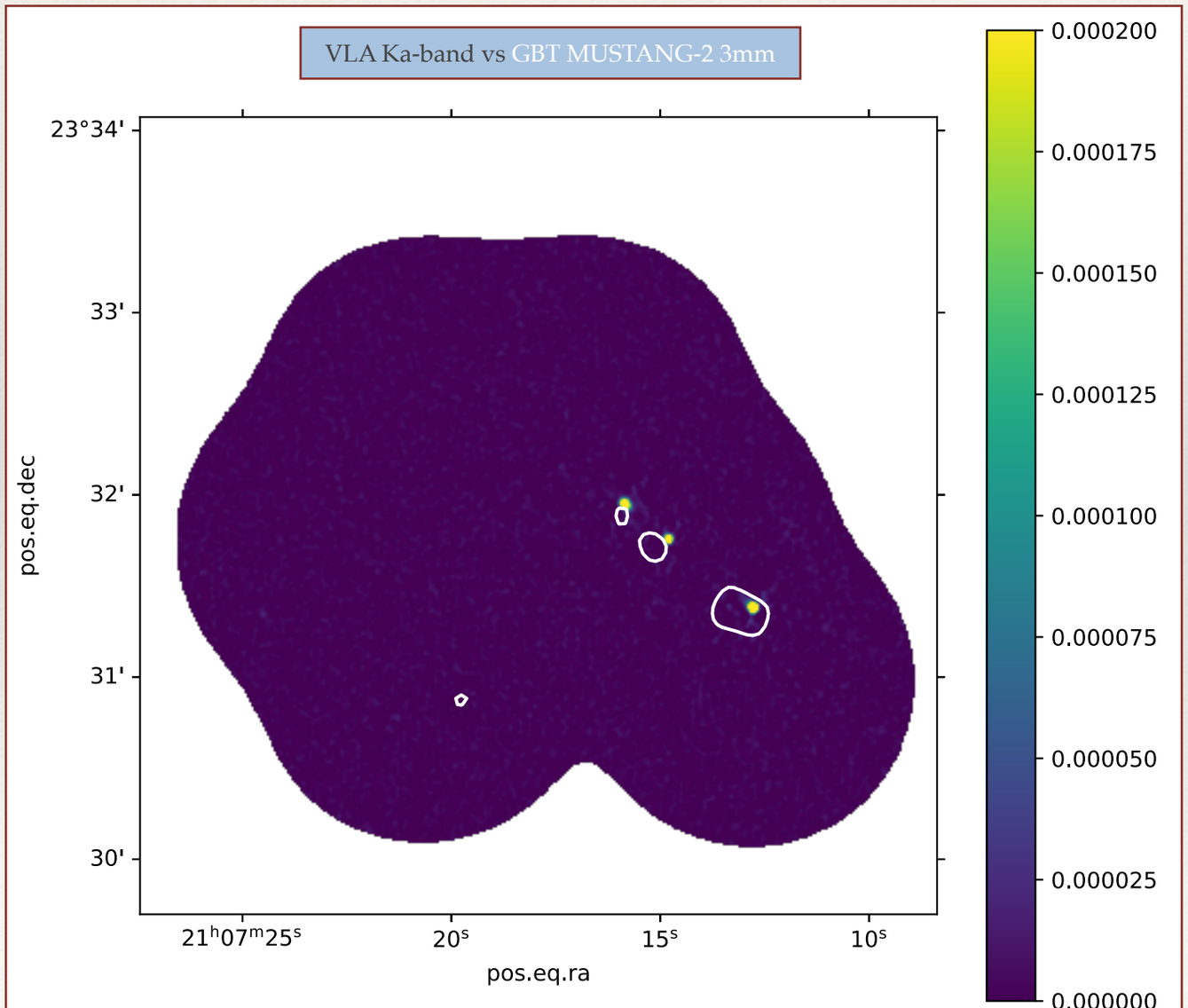
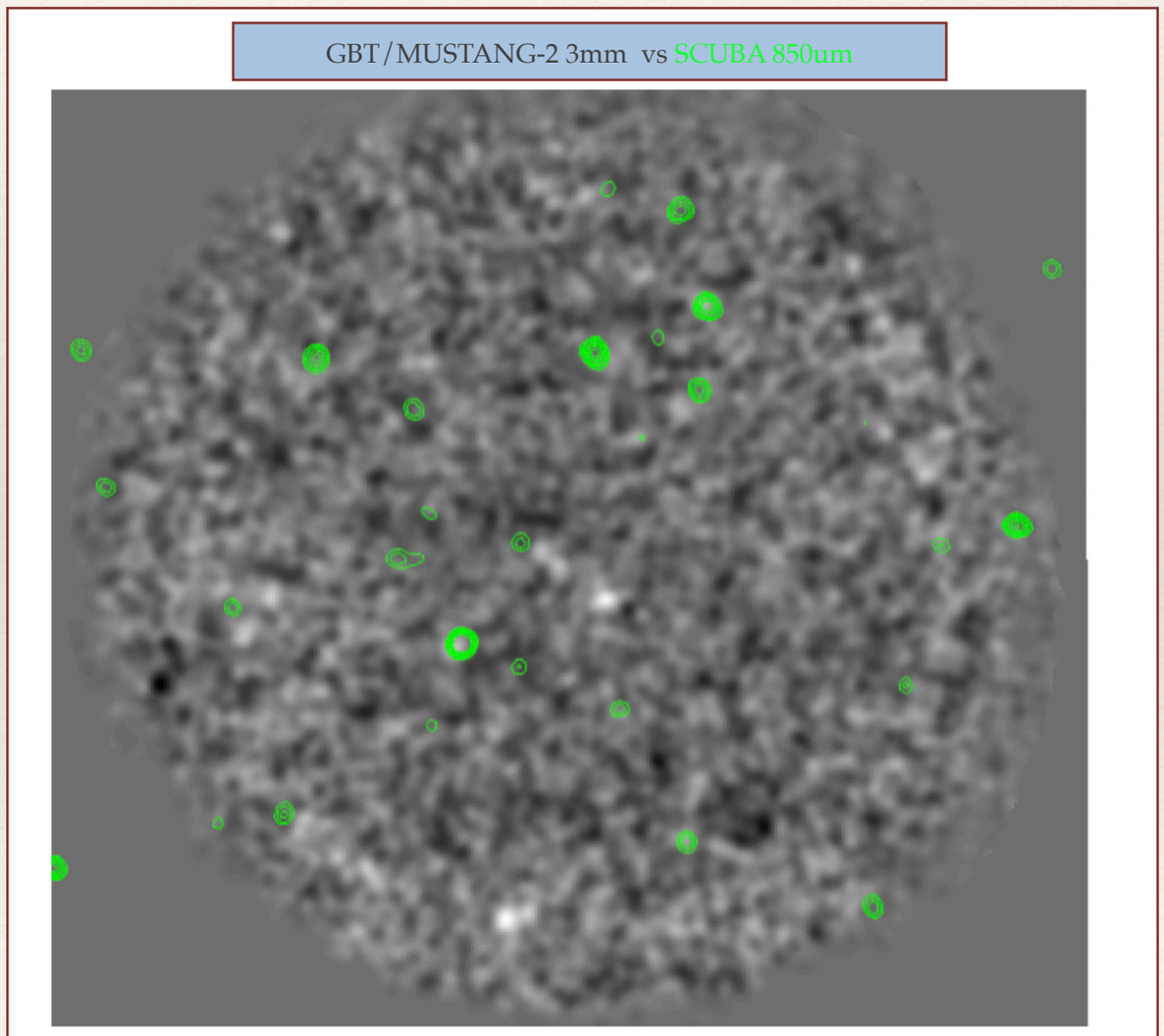




Radio Followup: 4C23.56 (z=2.48)

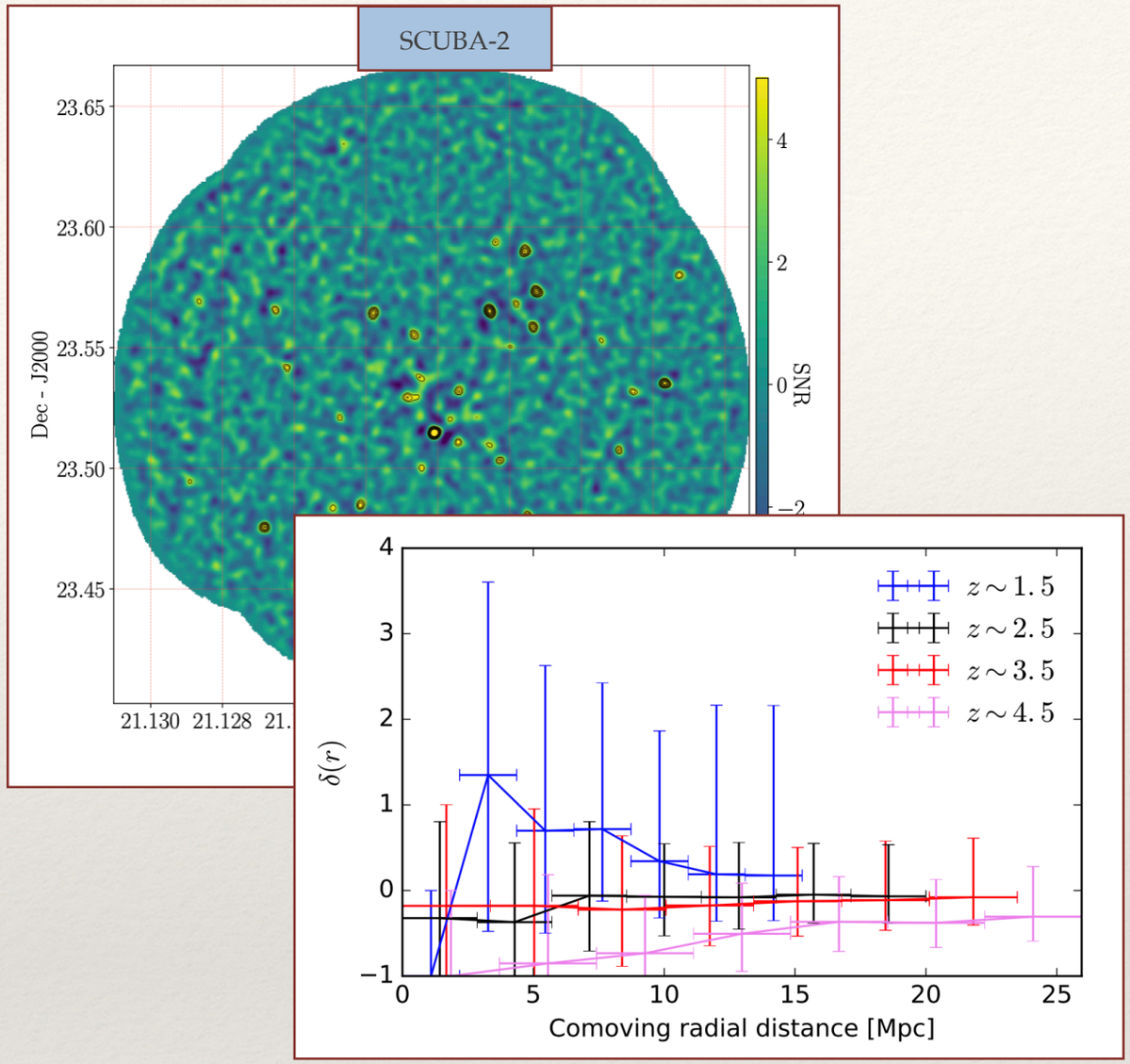
- Completed 30hr VLA Ka-band program for blind CO survey of 4C23.56 (**VLA-21A-294**)
- Lead by PhD student **Dazhi Zhou, DAWN**
- No CO lines detected



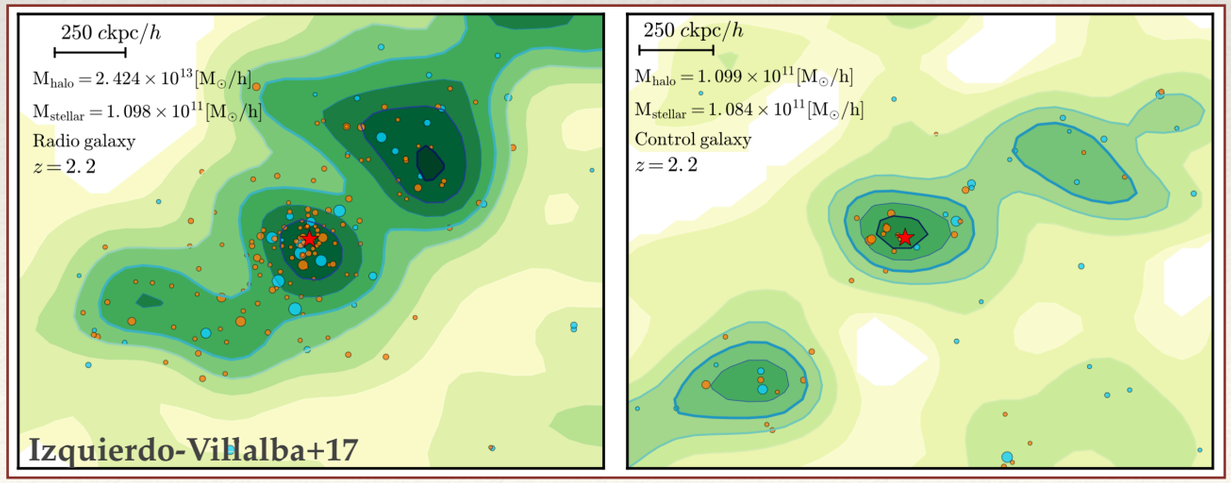


RAGERS - more to come

- We still do not have an adequate census of the submm environments of HzRGs
- Upon completion RAGERS will be the largest submm survey to date of the dusty Mpc-Scale environments around HzRGs
- RAGERS will provided a much needed comparison with radio-quiet galaxies



- Address evolutionary trends in SMG overdensities with redshift, stellar mass, and radio power. Trends that are only weakly constrained with current data.
- Coupled with simulations this will lead to a better understanding of proto-cluster growth in the presence/absence of powerful AGN and the interplay between AGN feedback, stellar mass and the IGM



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