Growing in Dual

A SCUBA-2 Survey on Quasars hosting Lyman Alpha Nebula at Cosmic Noon

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Marta NOWOTKA
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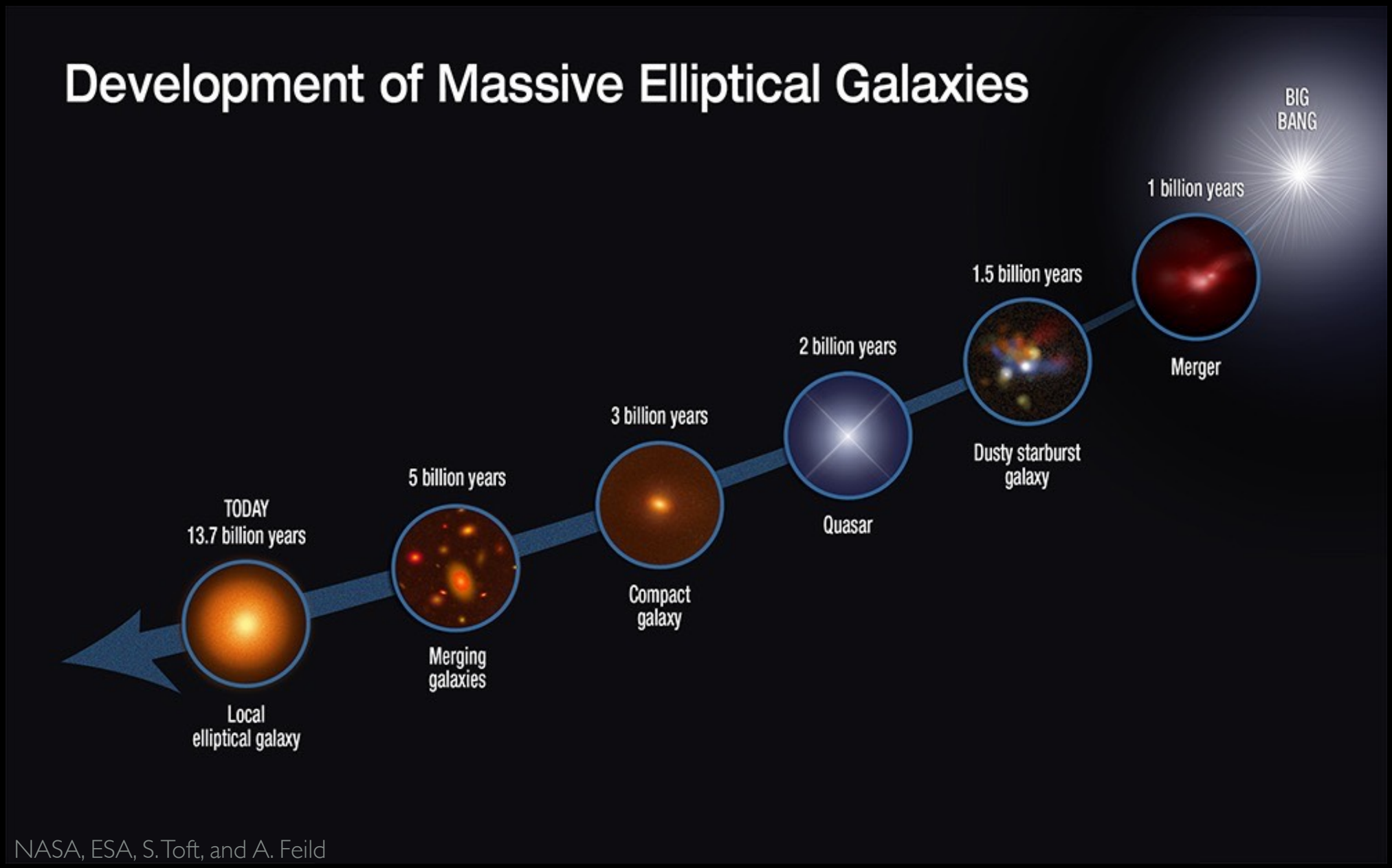
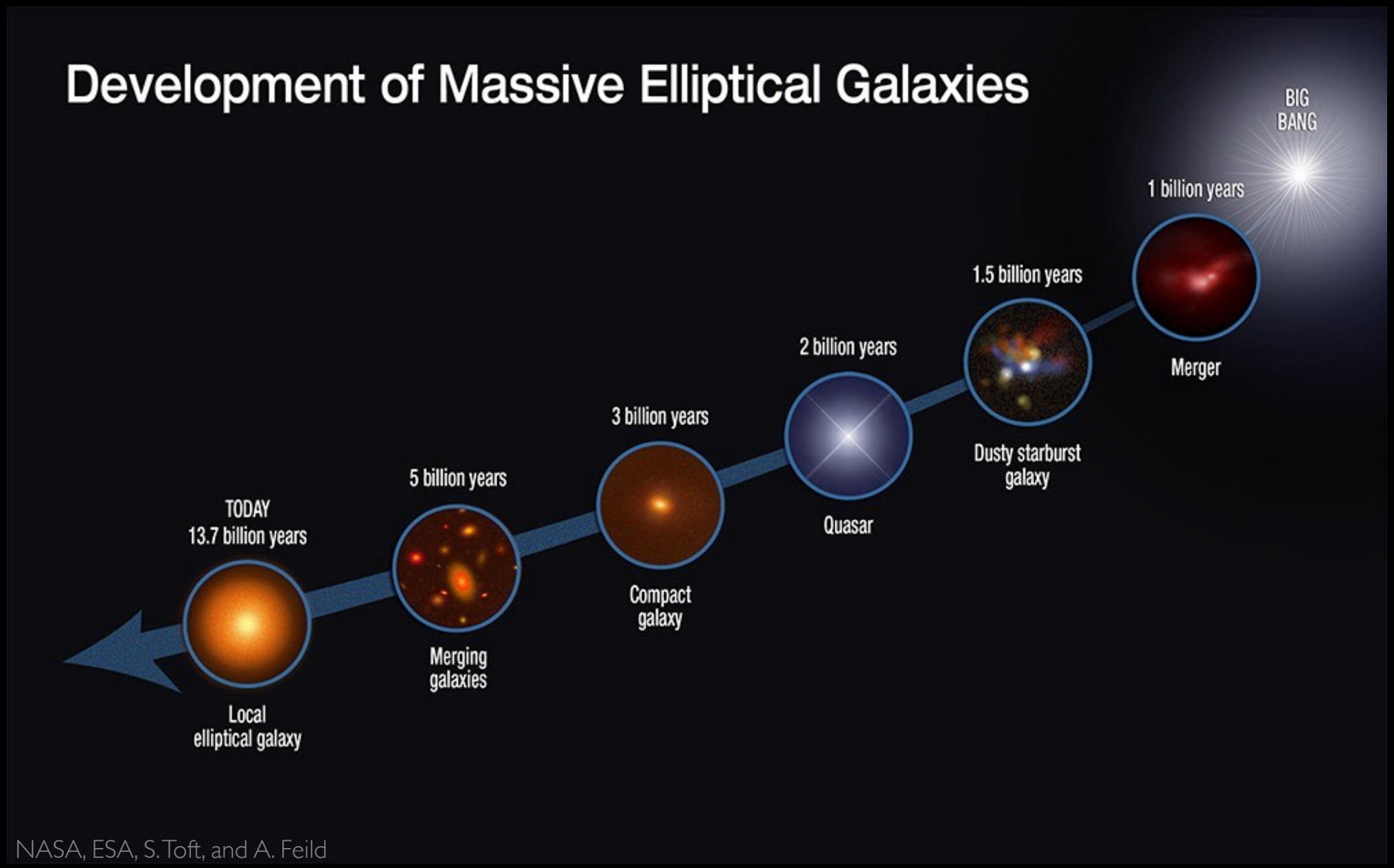
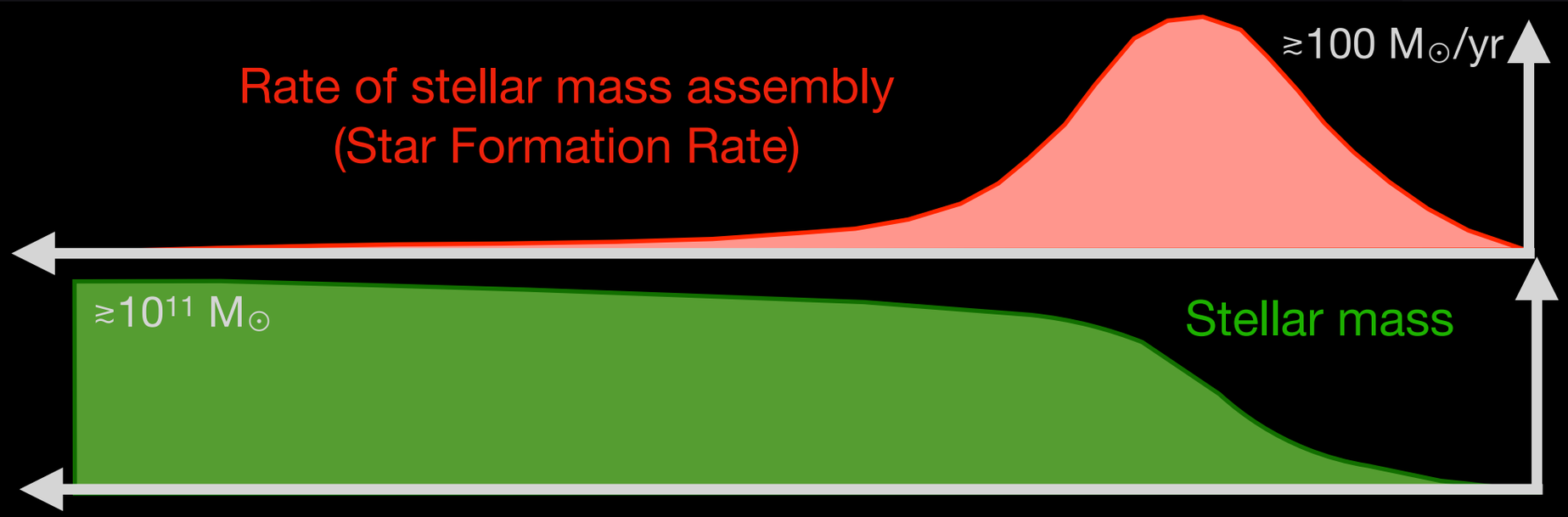
MOST 科技部 Ministry of Science and Technology

中央研究院 天文及天文物理研究所 ACADEMIA SINICA Institute of Astronomy and Astrophysics

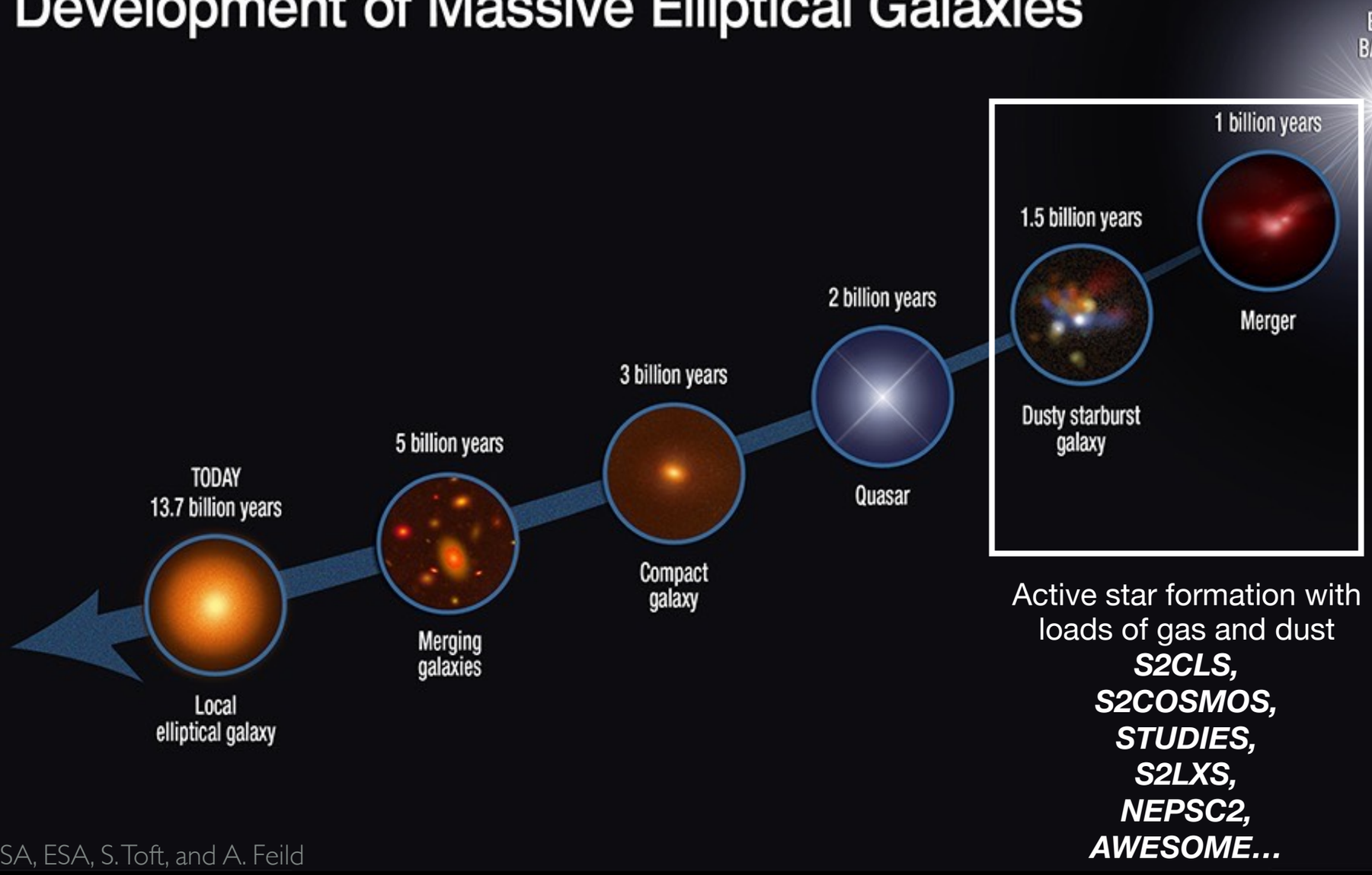


NASA, ESA, S. Toft, and A. Feild


Development of Massive Elliptical Galaxies
BIG BANG
1 billion years
Merger
1.5 billion years
Dusty starburst galaxy
2 billion years
Quasar
3 billion years
Compact galaxy
5 billion years
Merging galaxies
TODAY
13.7 billion years
Local elliptical galaxy
NASA, ESA, S. Toft, and A. Feild

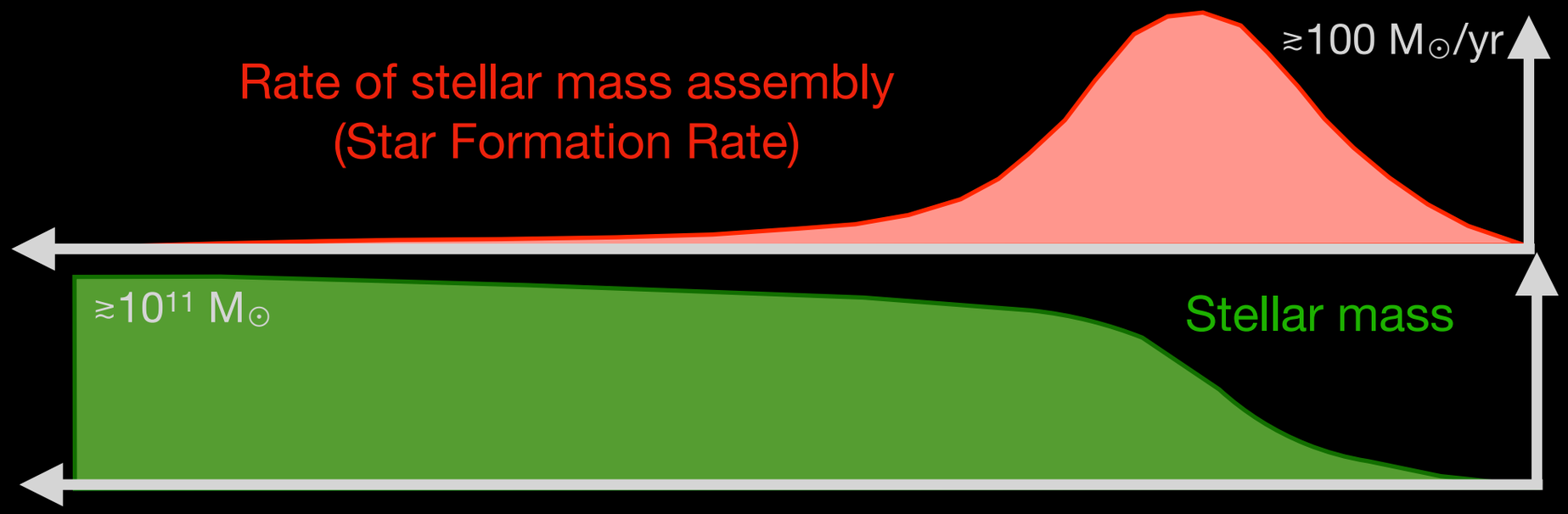

Rate of stellar mass assembly
(Star Formation Rate)
≈100 M⊙/yr
≈10¹¹ M⊙
Stellar mass

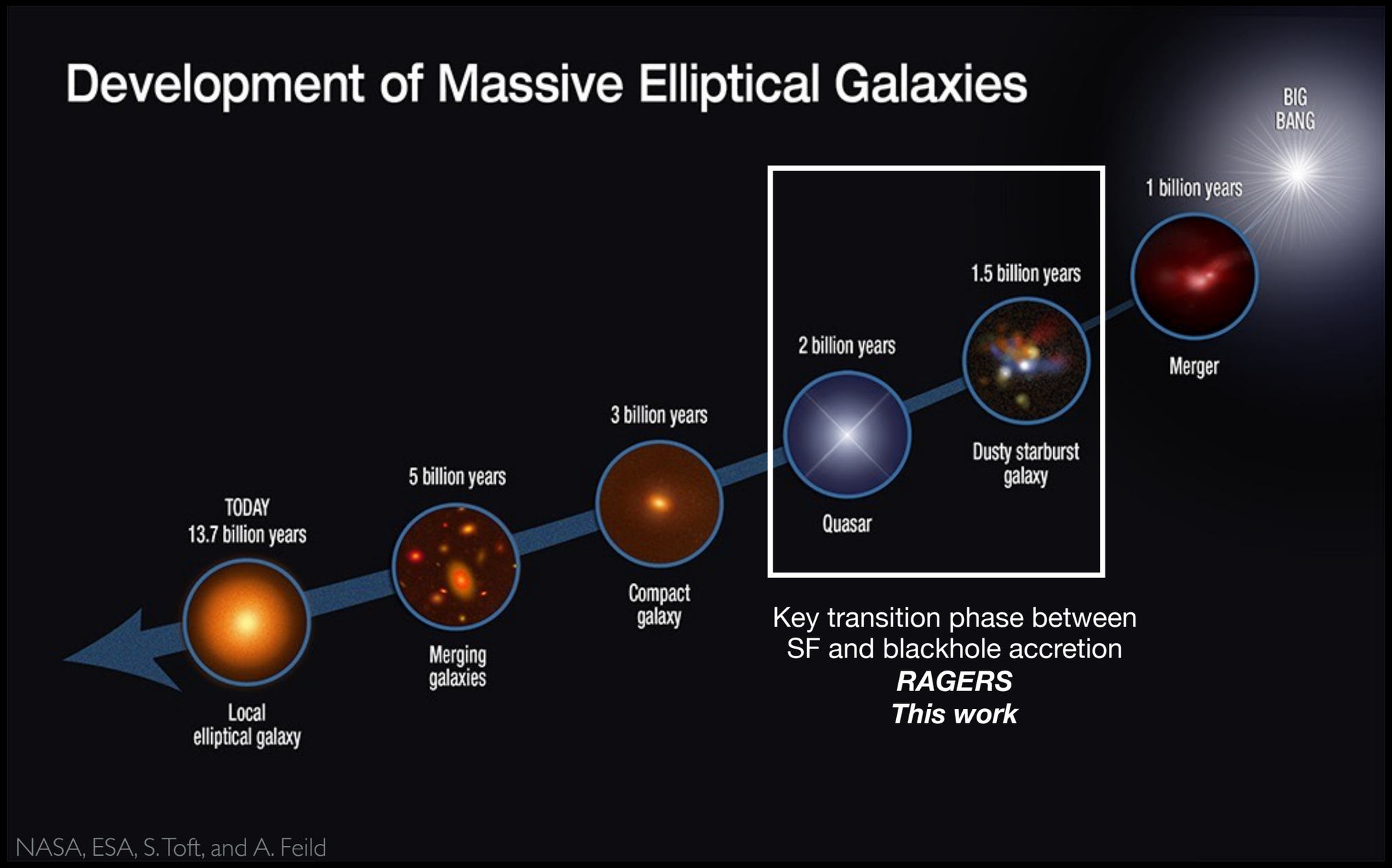
Development of Massive Elliptical Galaxies



Active star formation with loads of gas and dust
S2CLS, S2COSMOS, STUDIES, S2LXS, NEPSC2, AWESOME…

NASA, ESA, S. Toft, and A. Feild

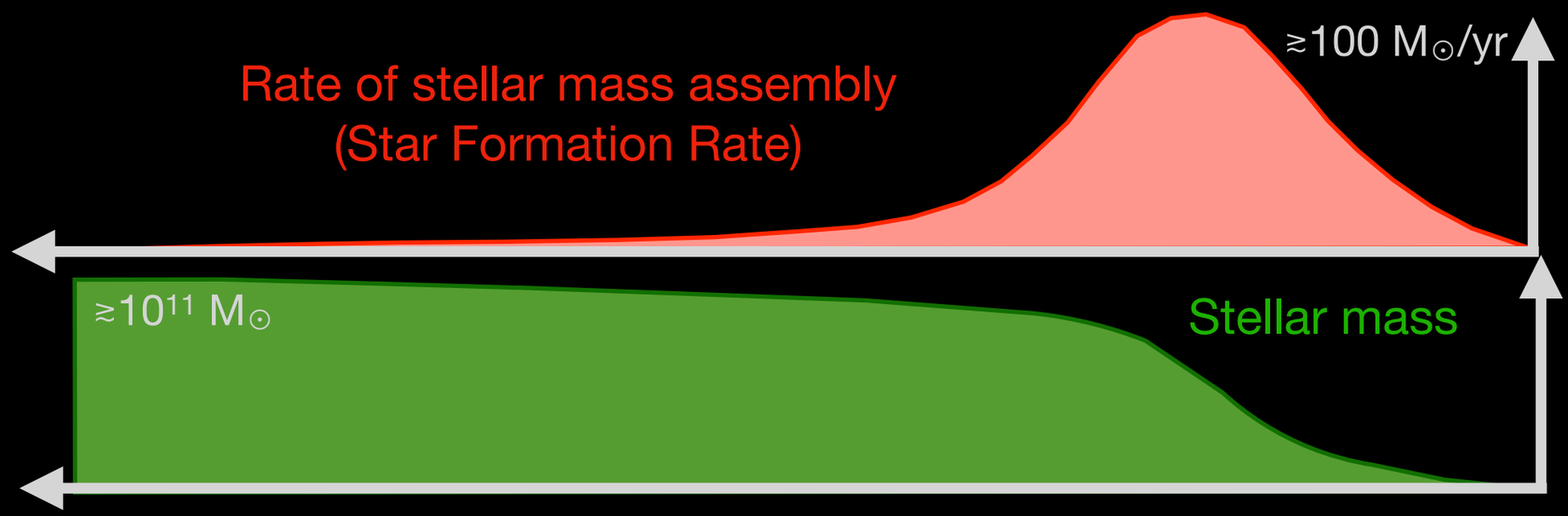




Key transition phase between SF and blackhole accretion

RAGERS

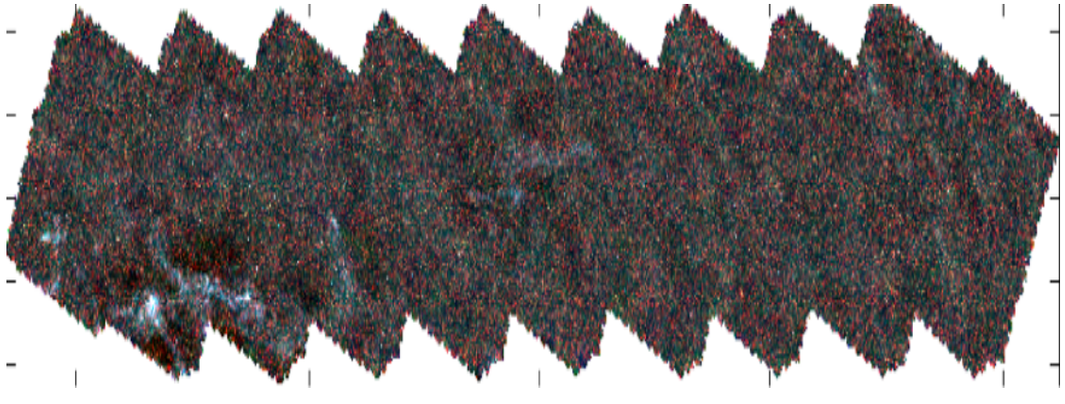
This work

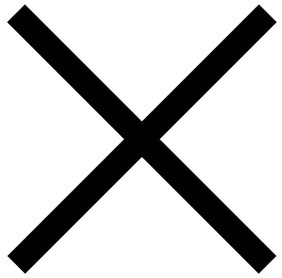


QSO-SMG coevolution

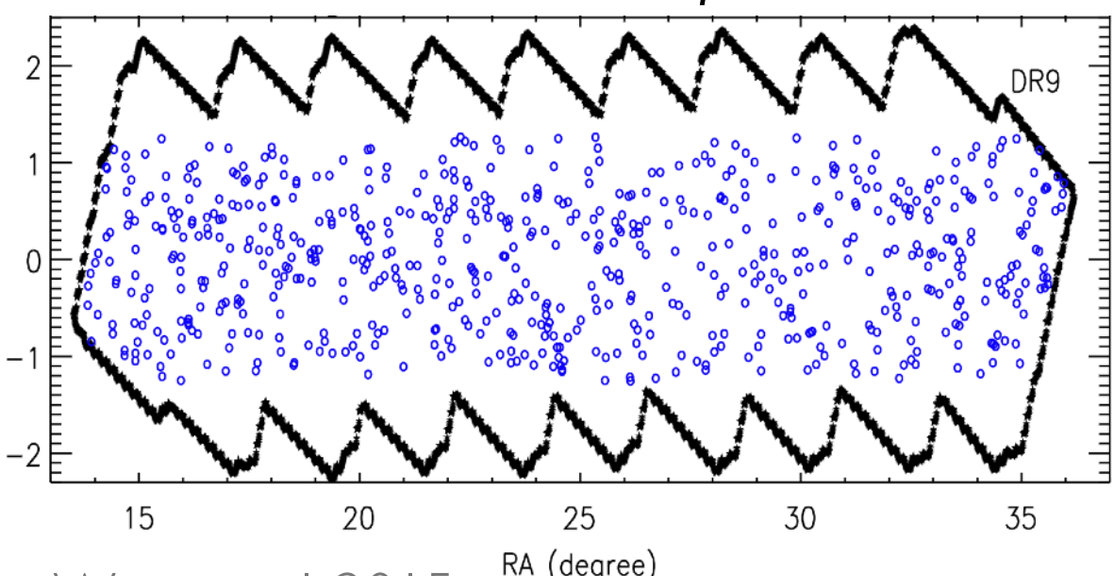
Evidence from cross correlation

Herschel 250/350/500 micron





<z=2.5> SDSS quasars



Wang et al. 2015

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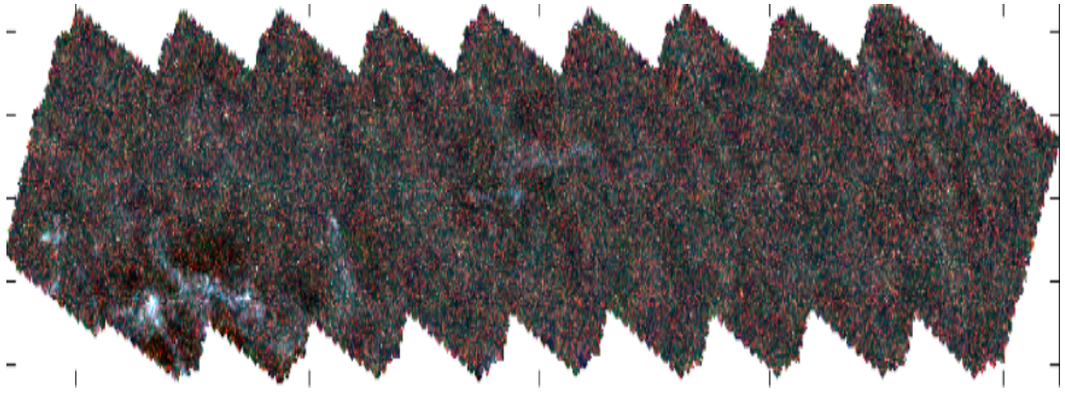

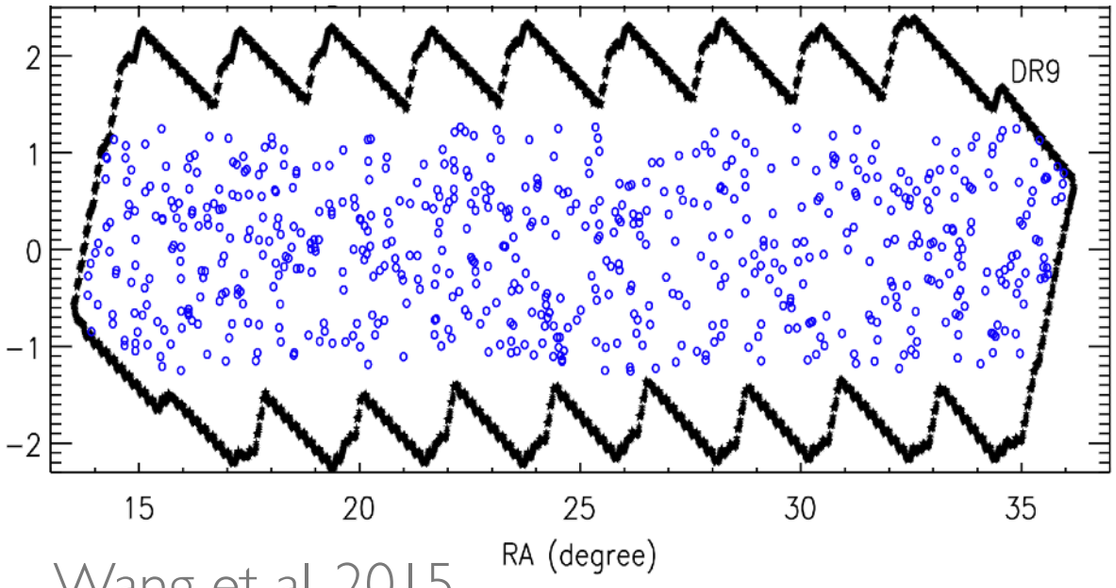

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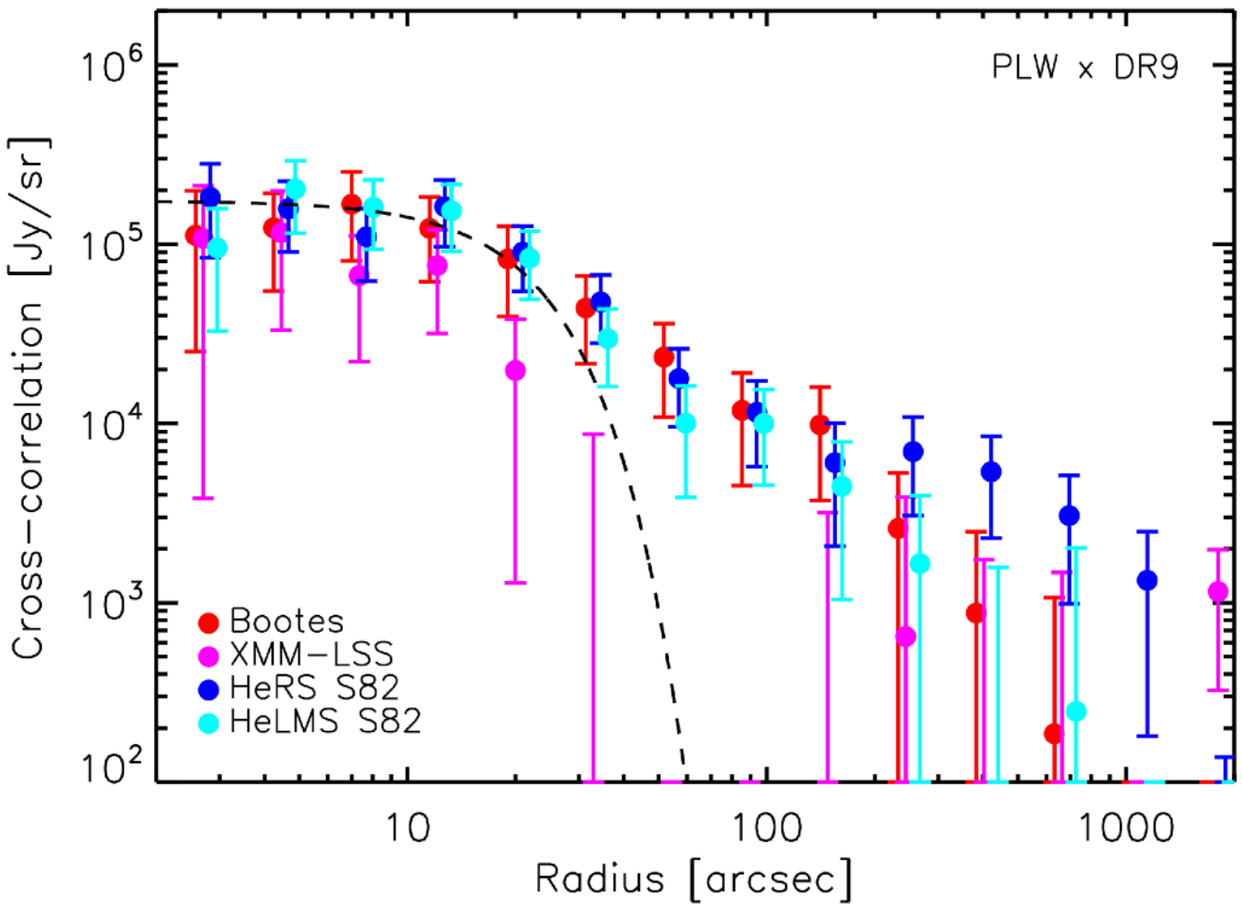

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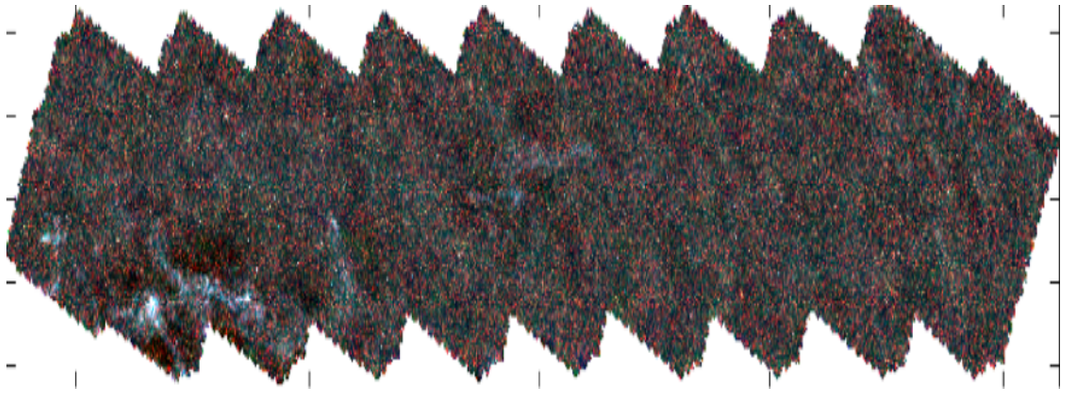

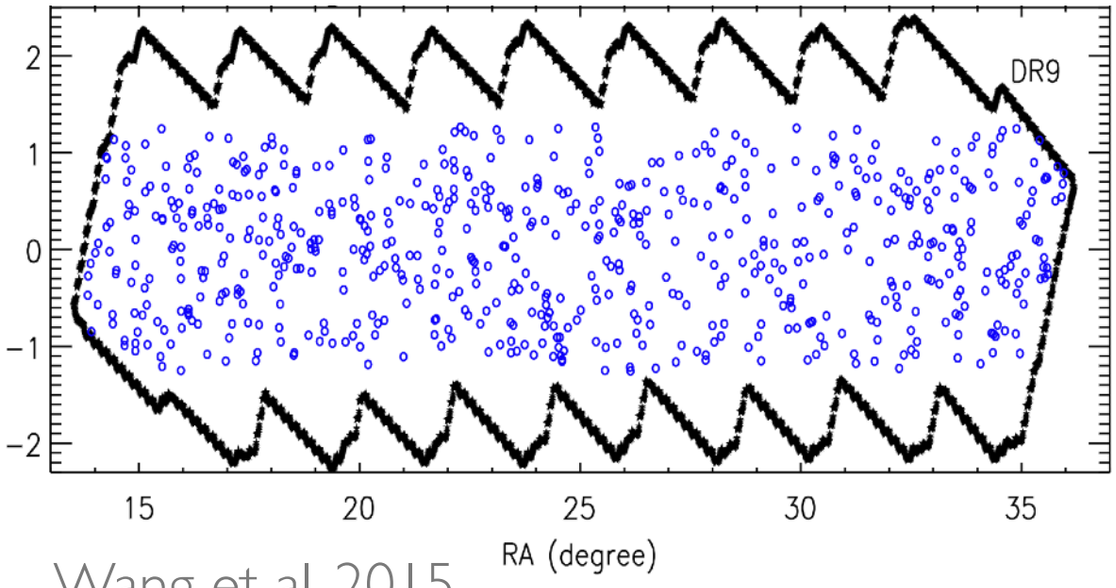

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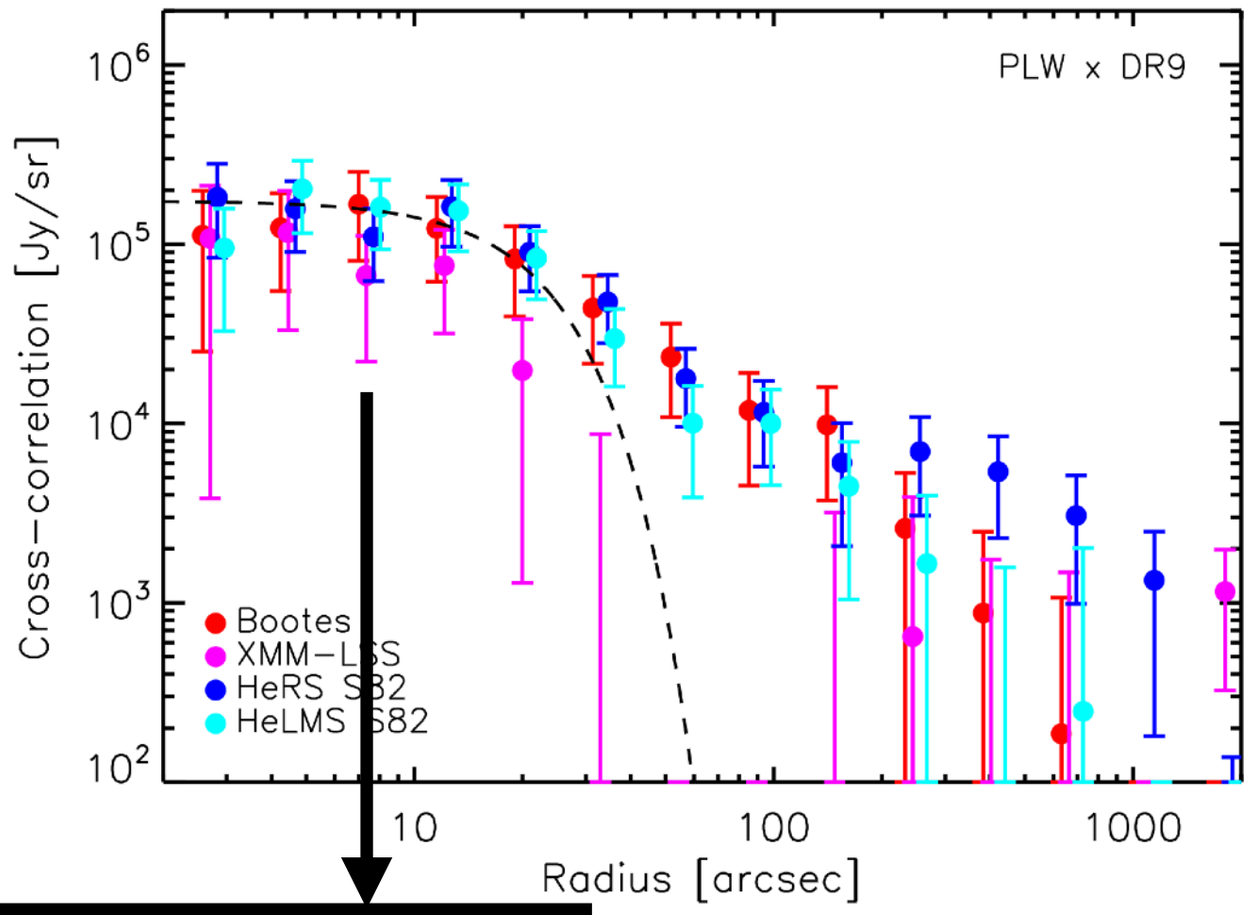

Emissions from quasars

Wang et al. 2015

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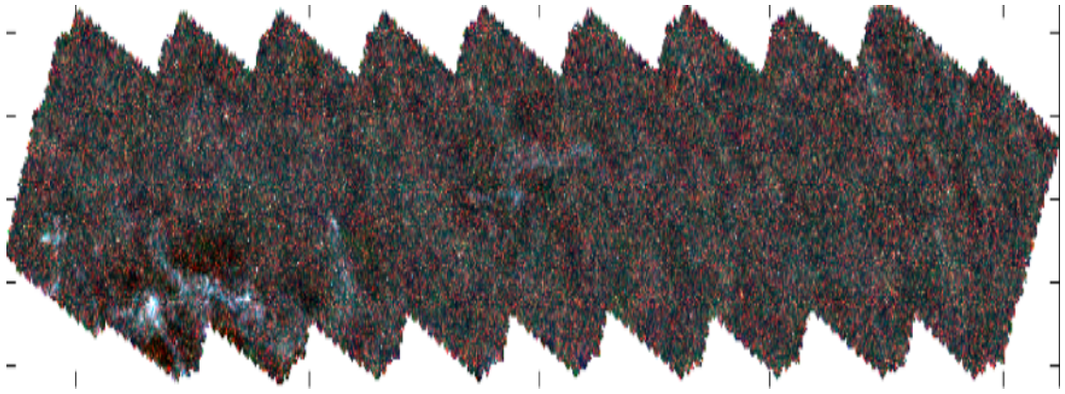

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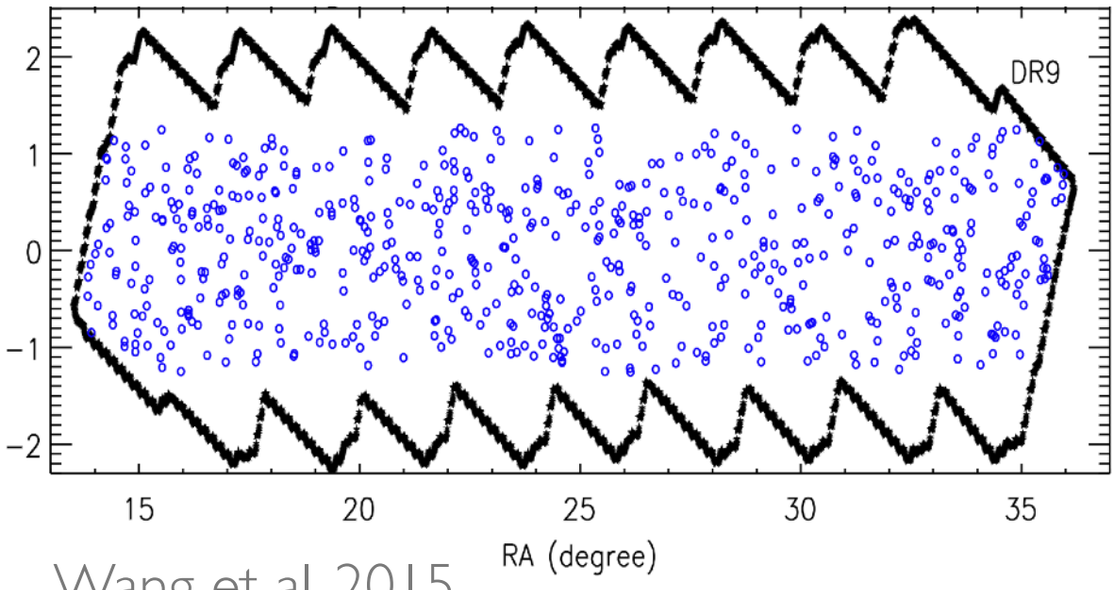
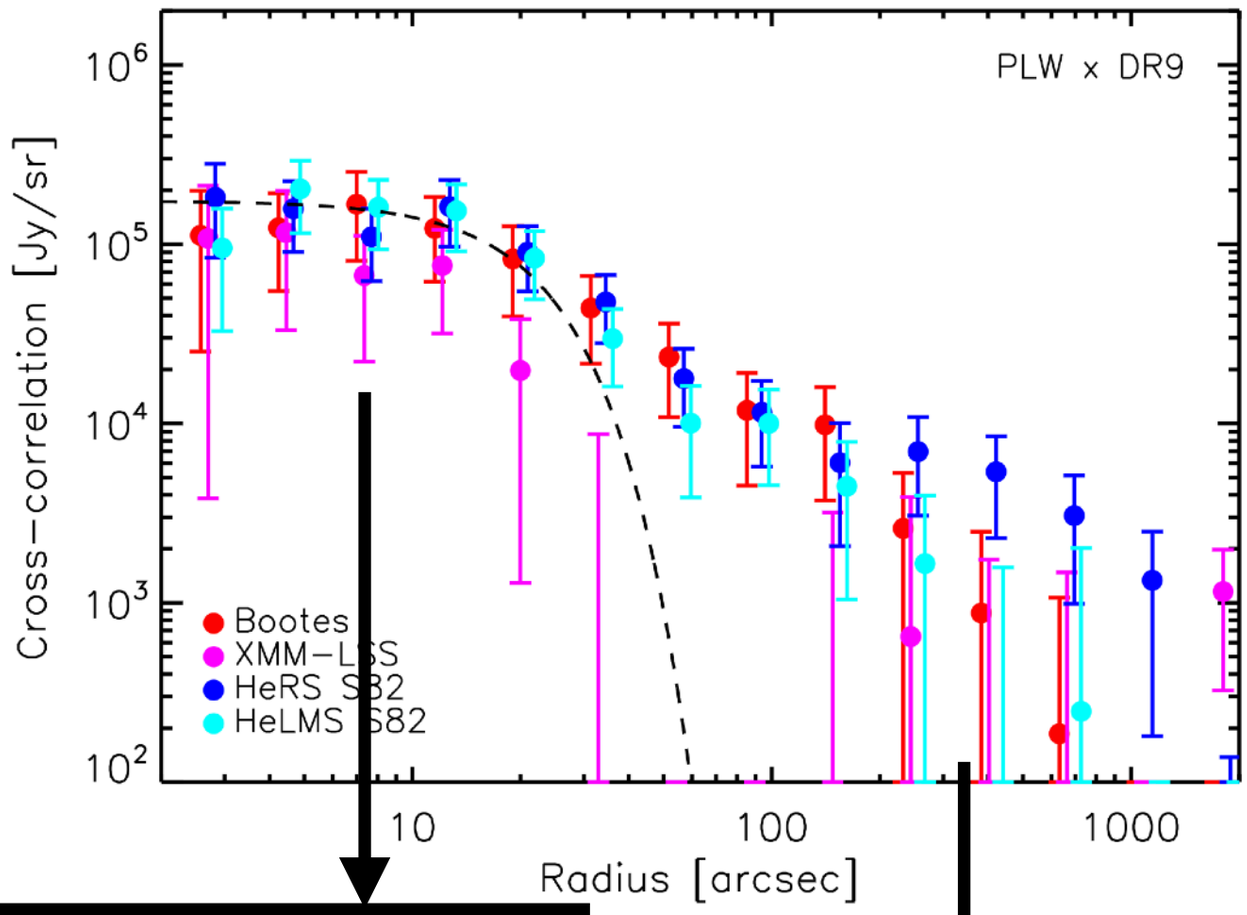




Emissions from quasars

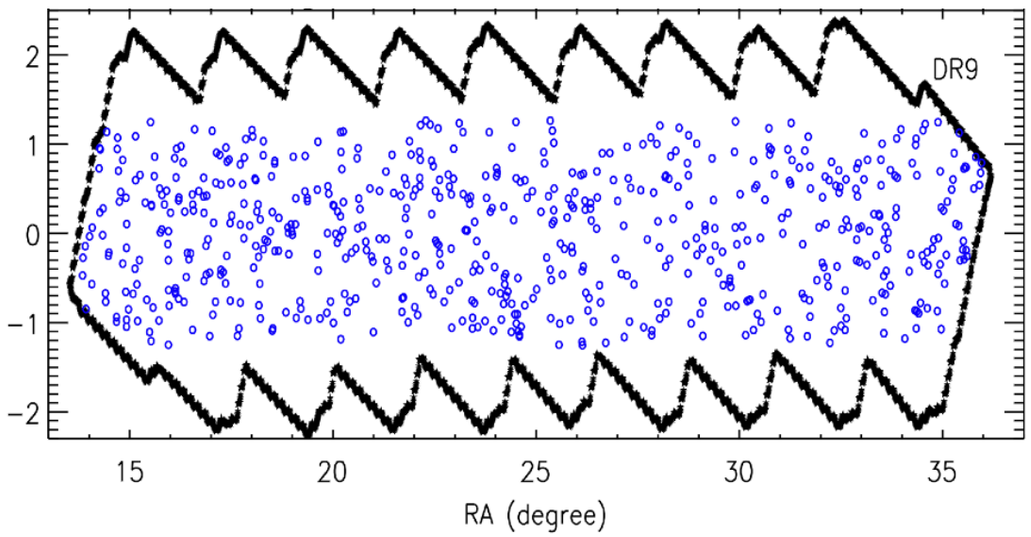
Coevolving SMGs at <~10 Mpc scales

Wang et al. 2015

Halos hosting QSOs / SMGs

Two-point auto-correlation functions

$$\xi_2(\Delta) = \frac{1}{V}\int d^3x\, \delta(\mathbf{x})\delta(\mathbf{x}+\mathbf{\Delta}).$$



Lim, CCC et al. 2020

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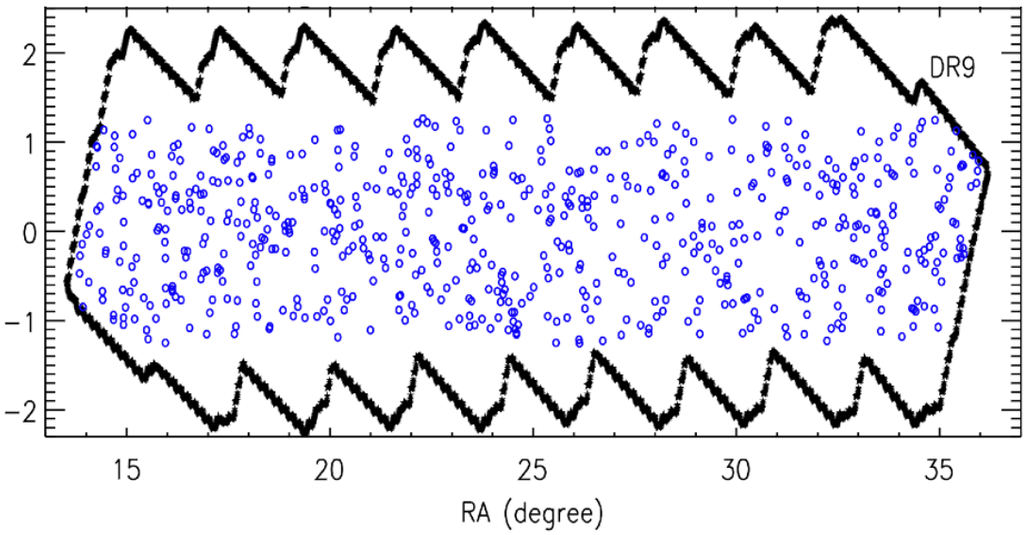

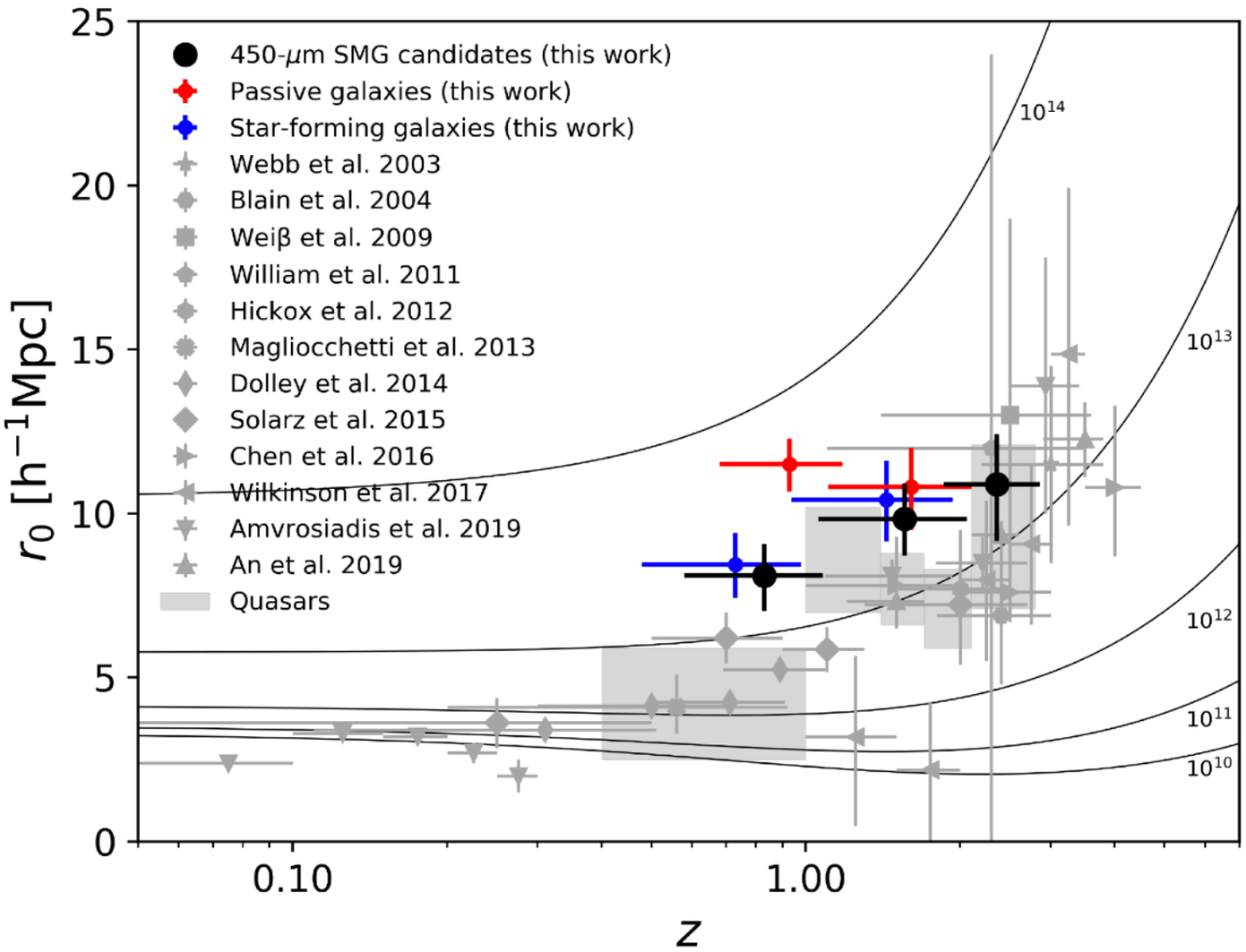

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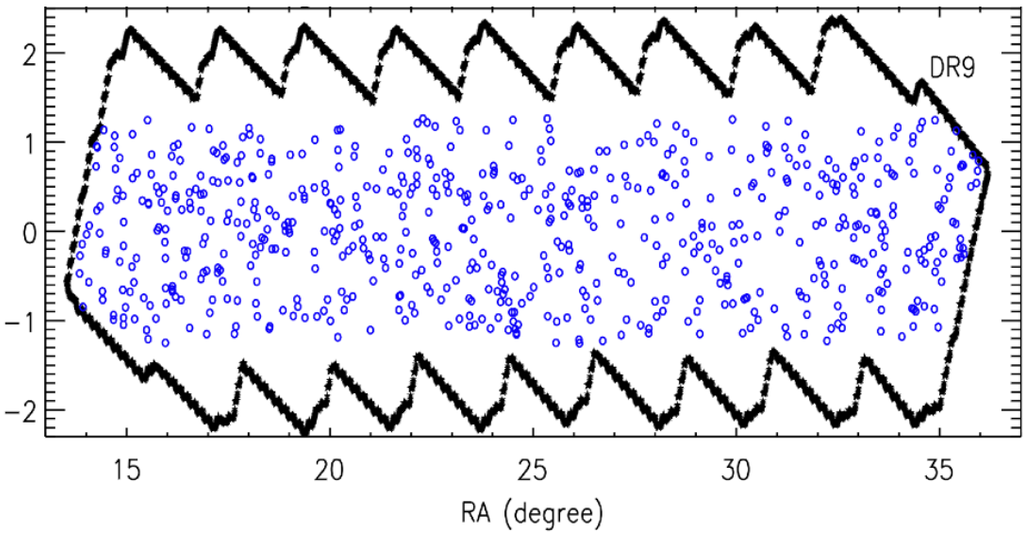

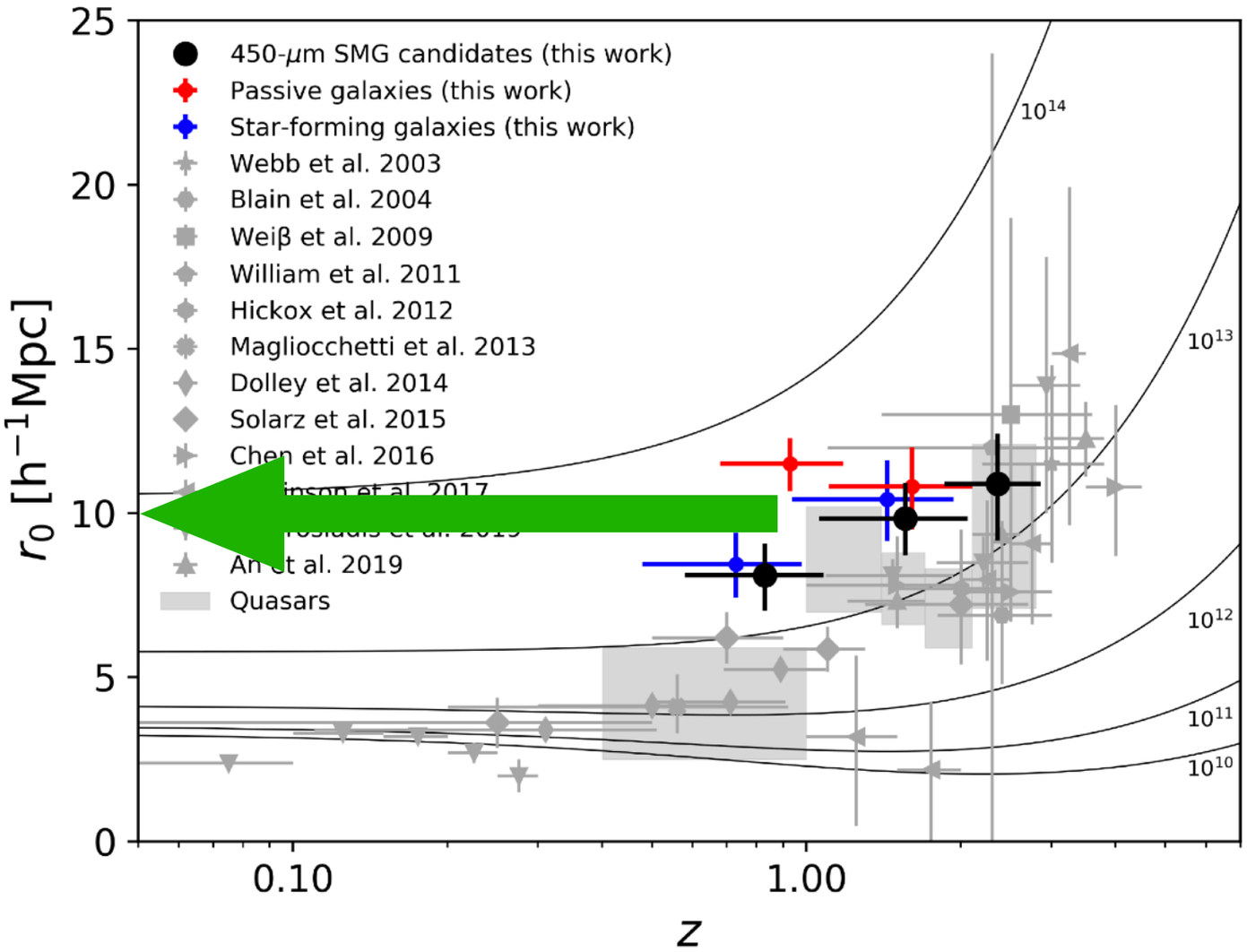

Lim, CCC et al. 2020

Halos hosting QSOs / SMGs

Both hosted by halos with ~10^13 solar masses
and would evolve into present day galaxy clusters

Two-point auto-correlation functions

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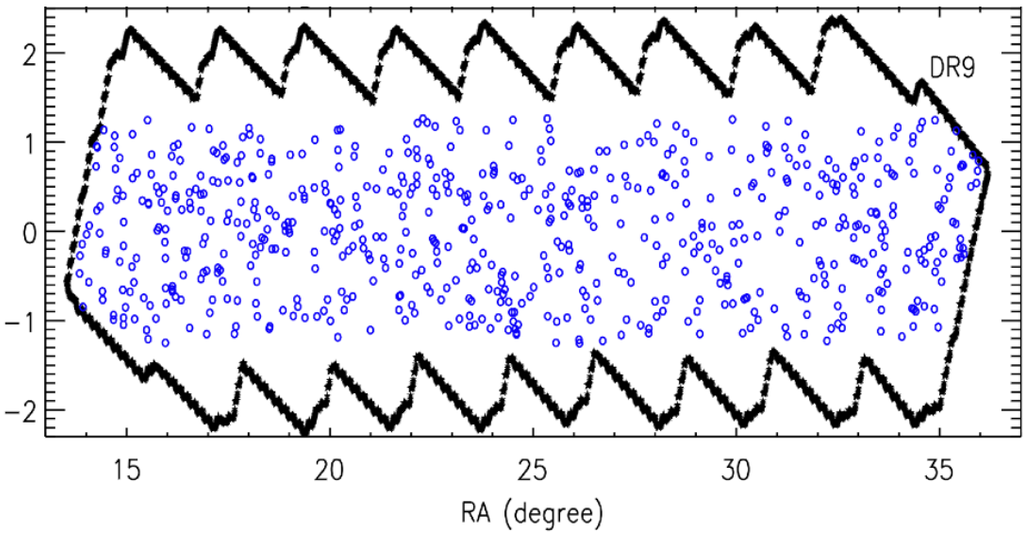
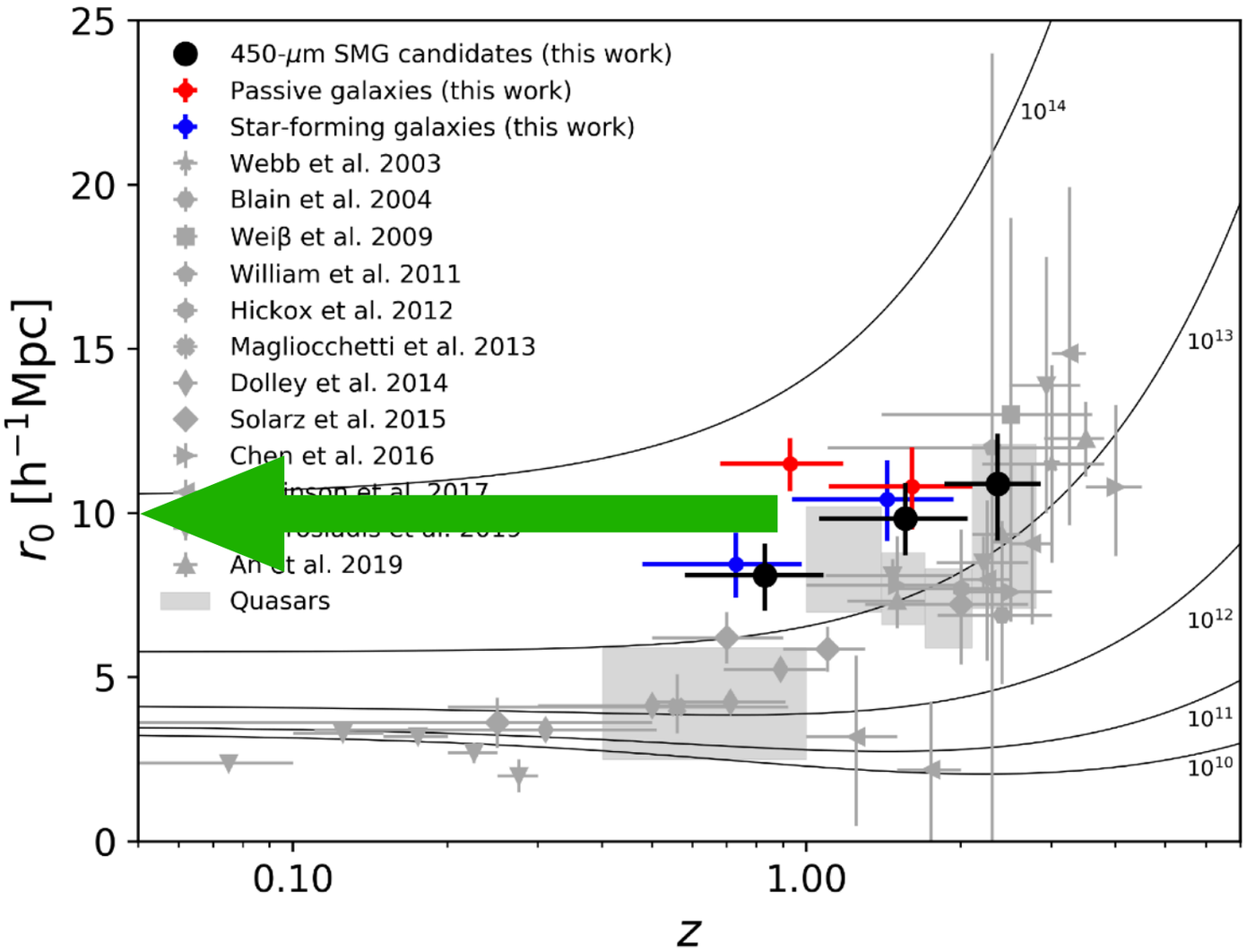
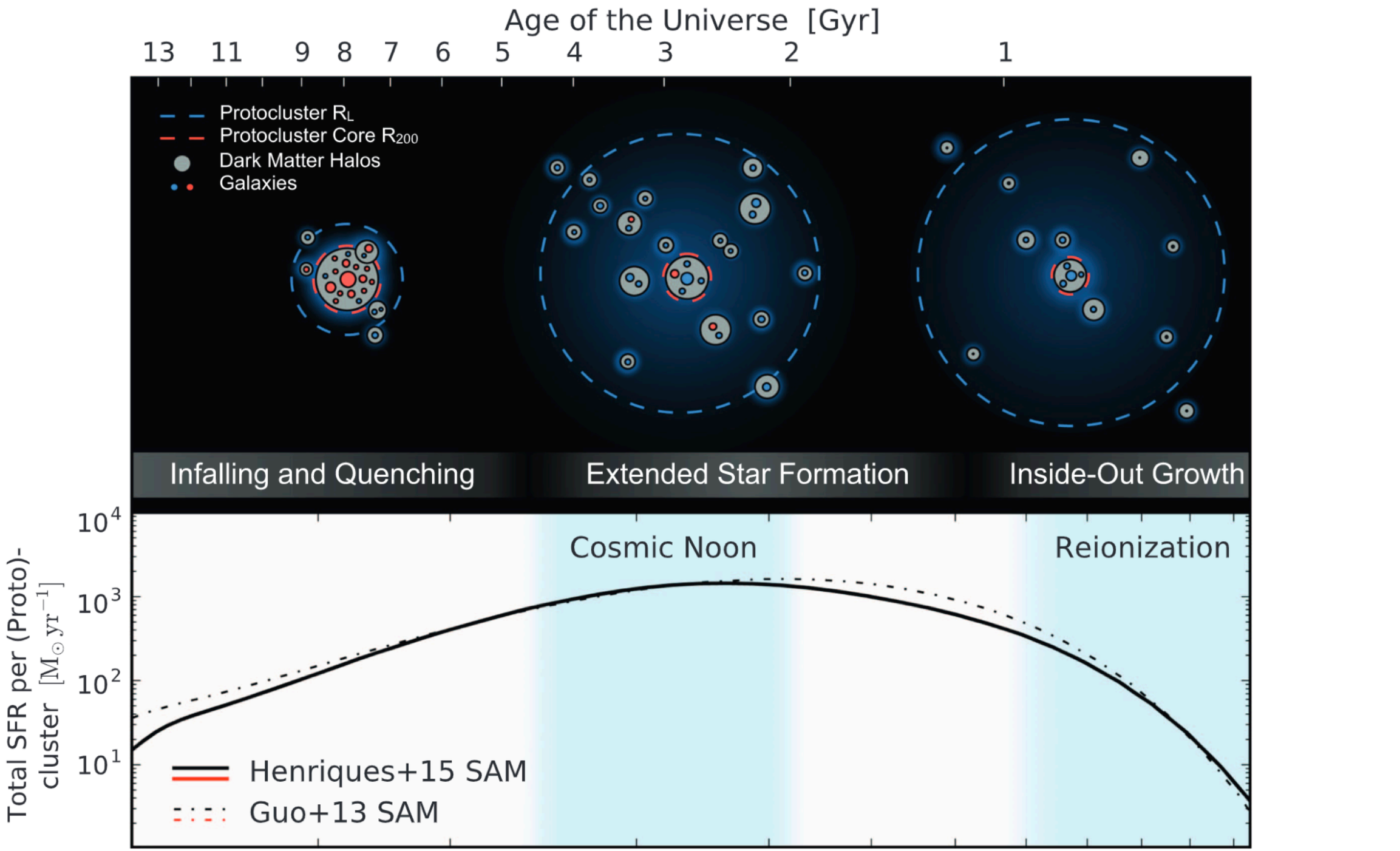




Lim, CCC et al. 2020

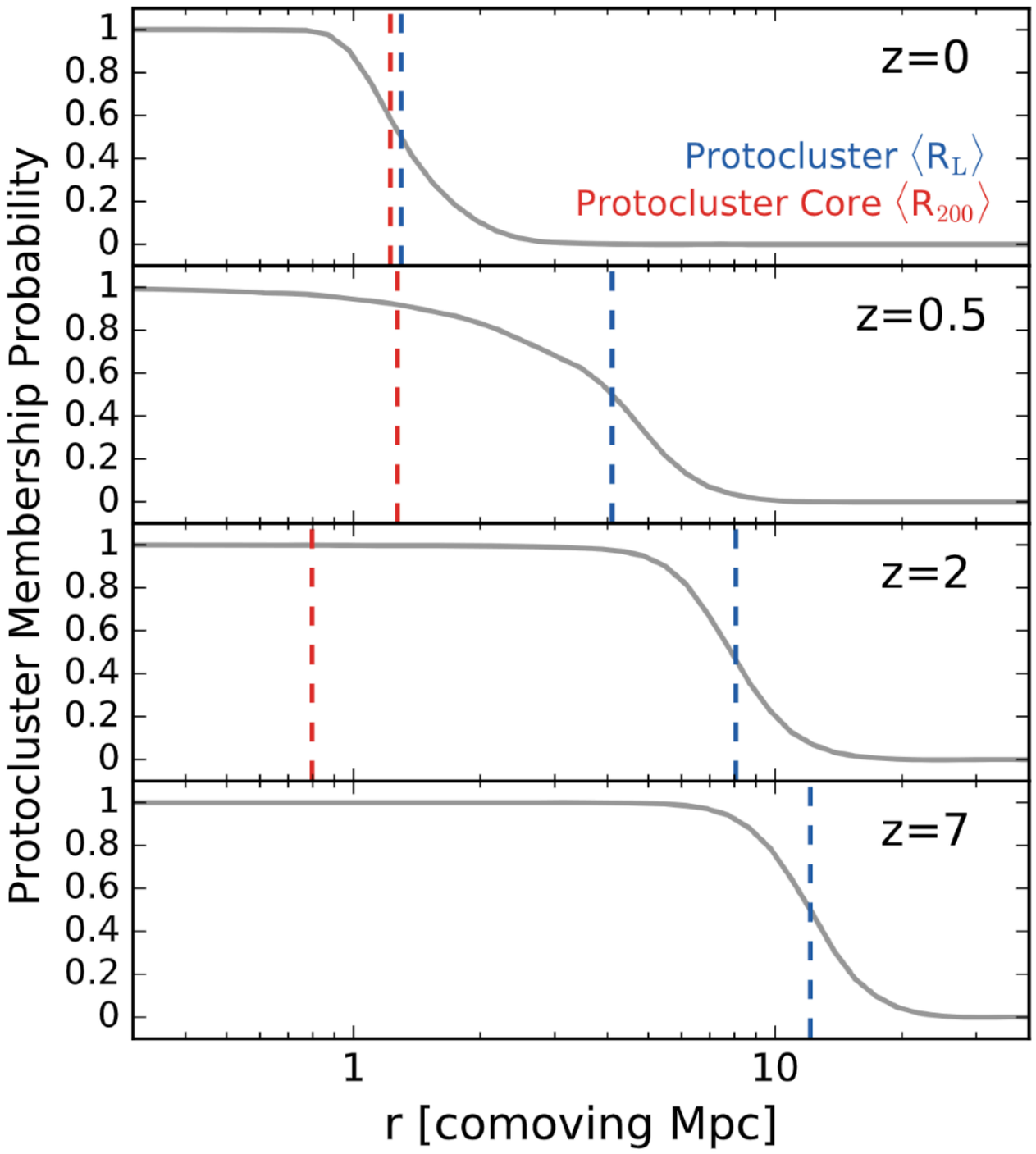
Theoretical perspectives on proto-clusters



Chiang et al. 2017

Theoretical perspectives on proto-clusters

Much more extended in the early times



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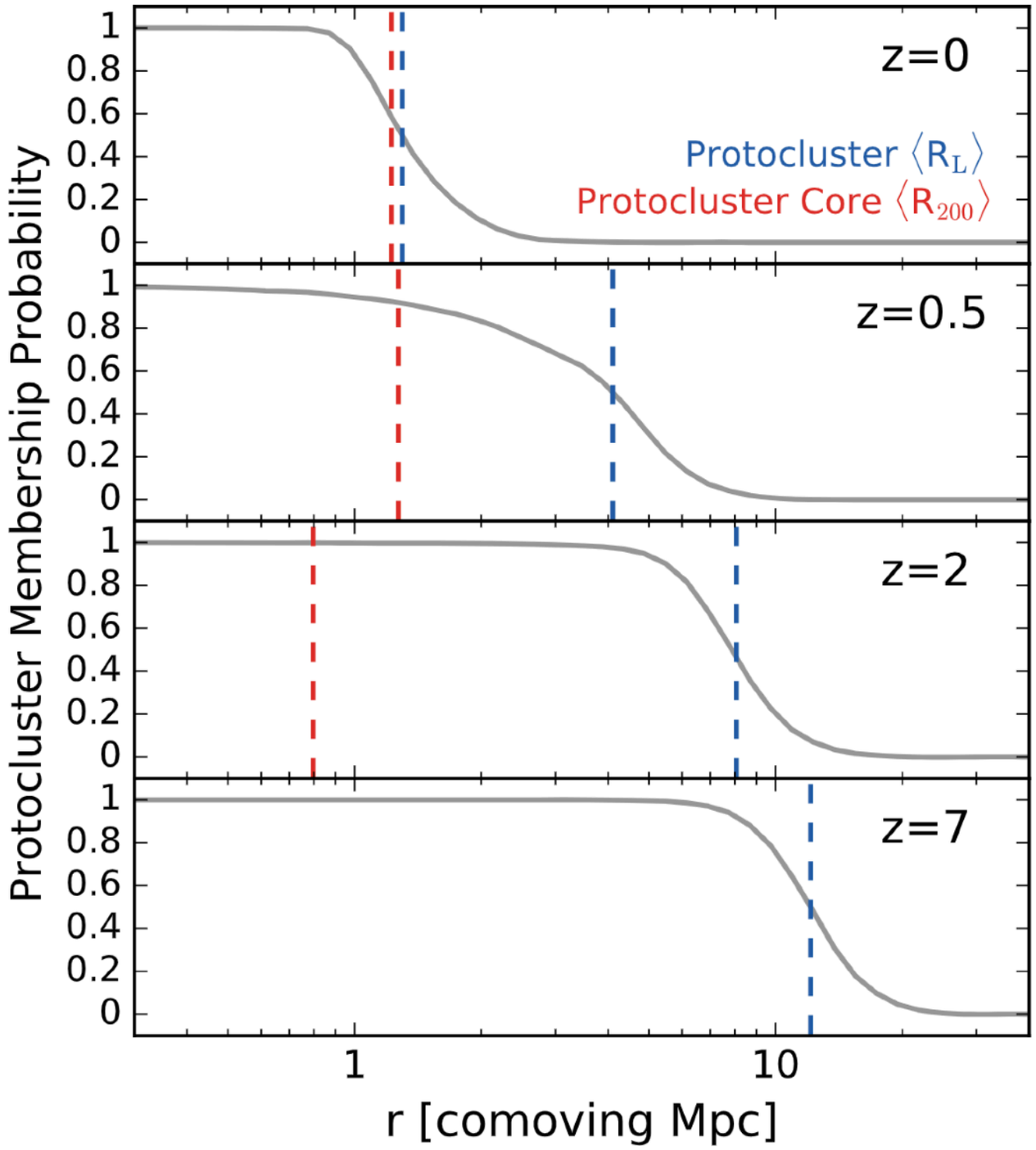
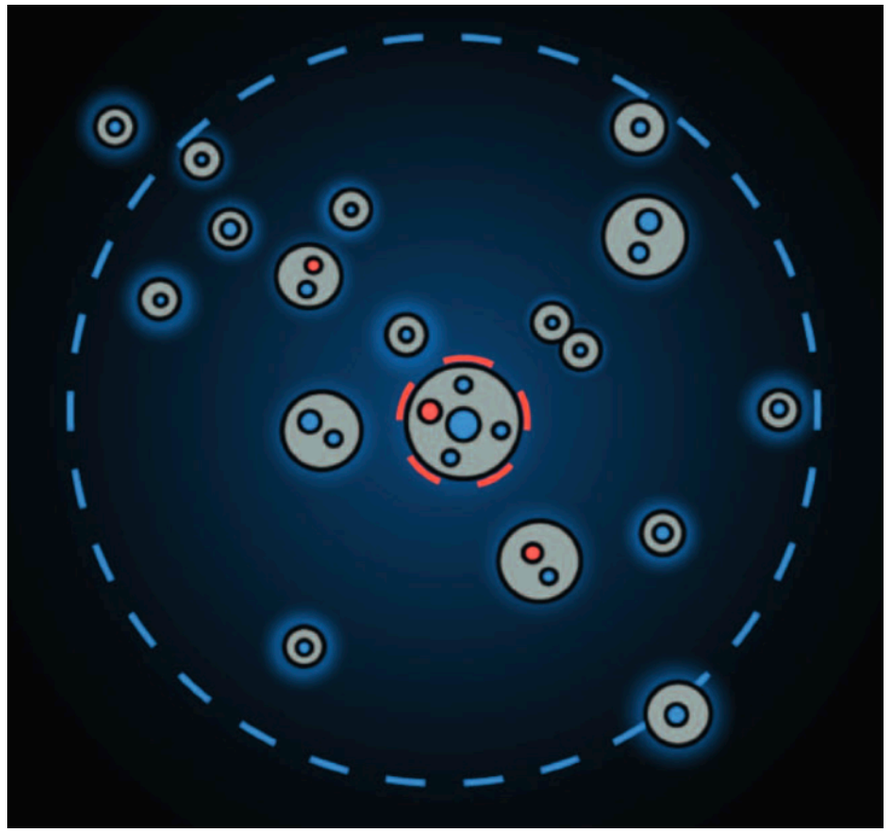


z~2-3



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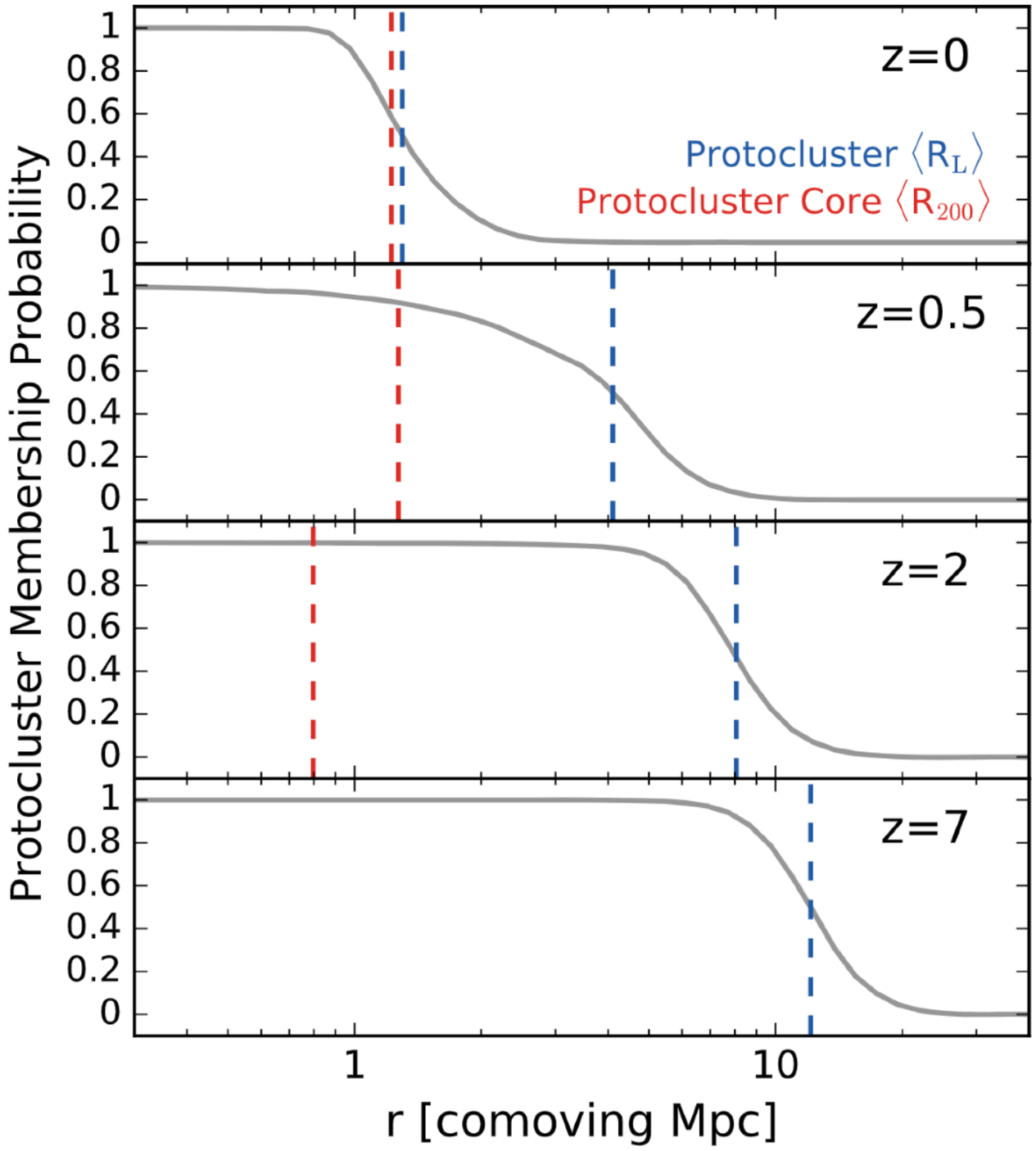

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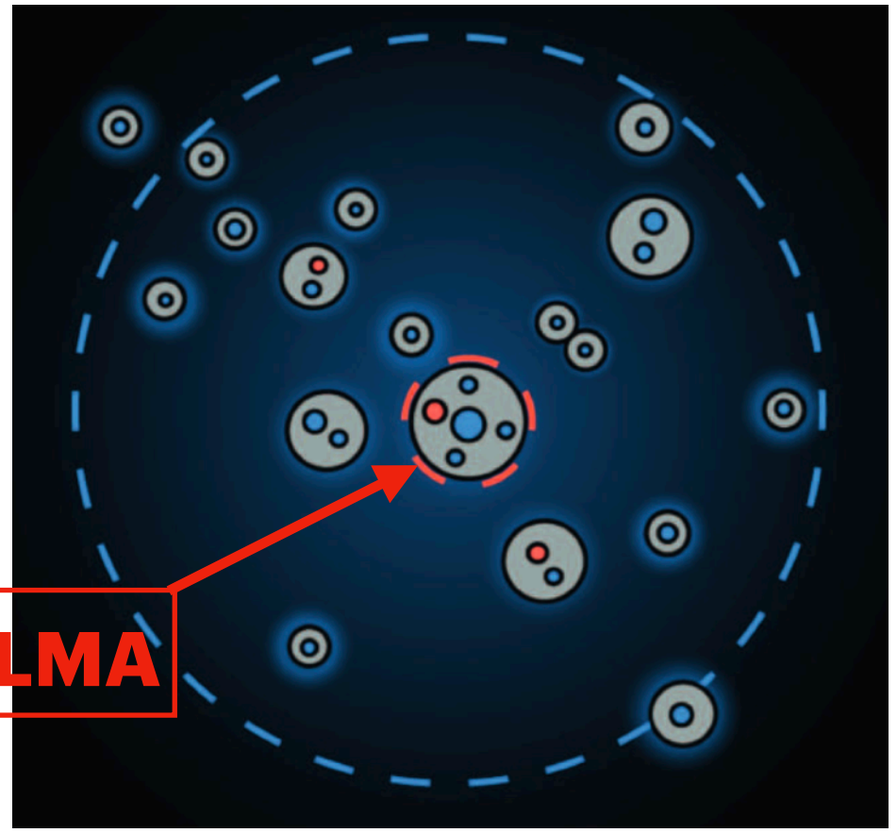

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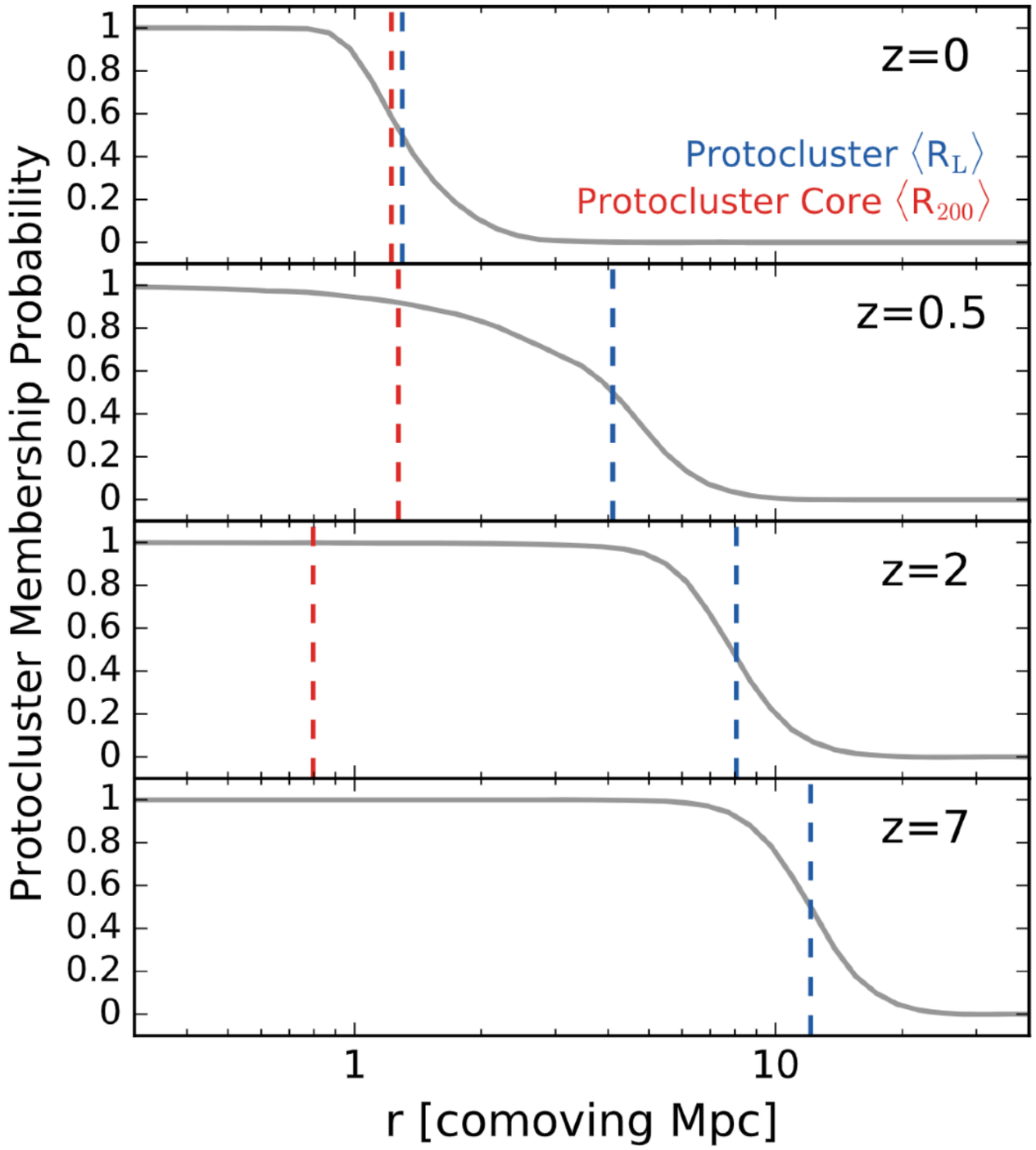

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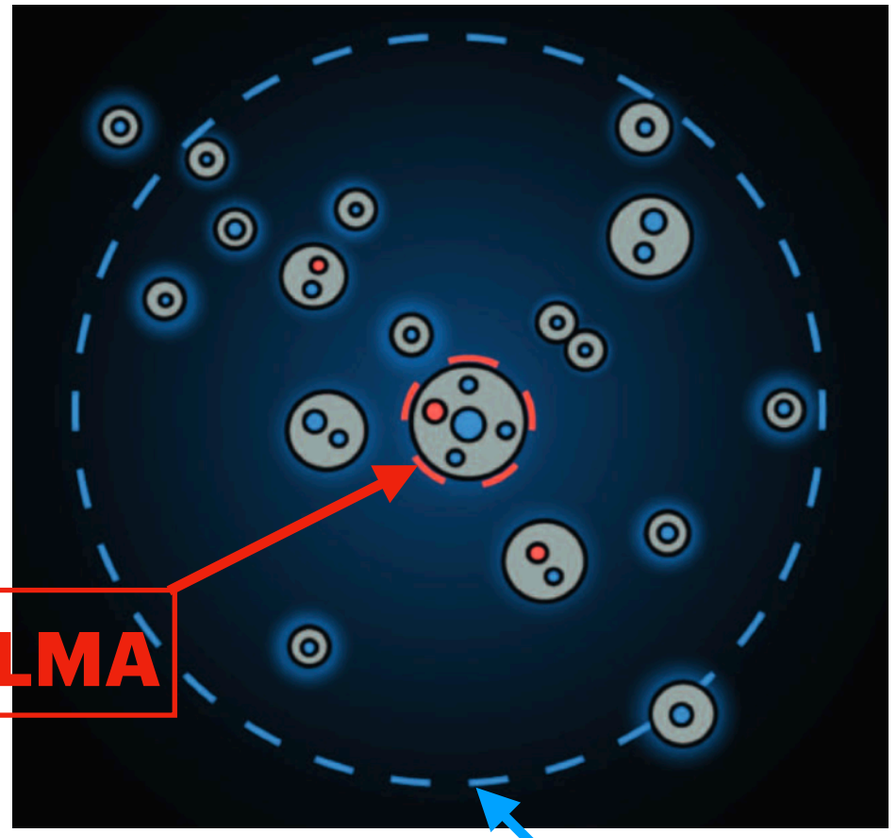


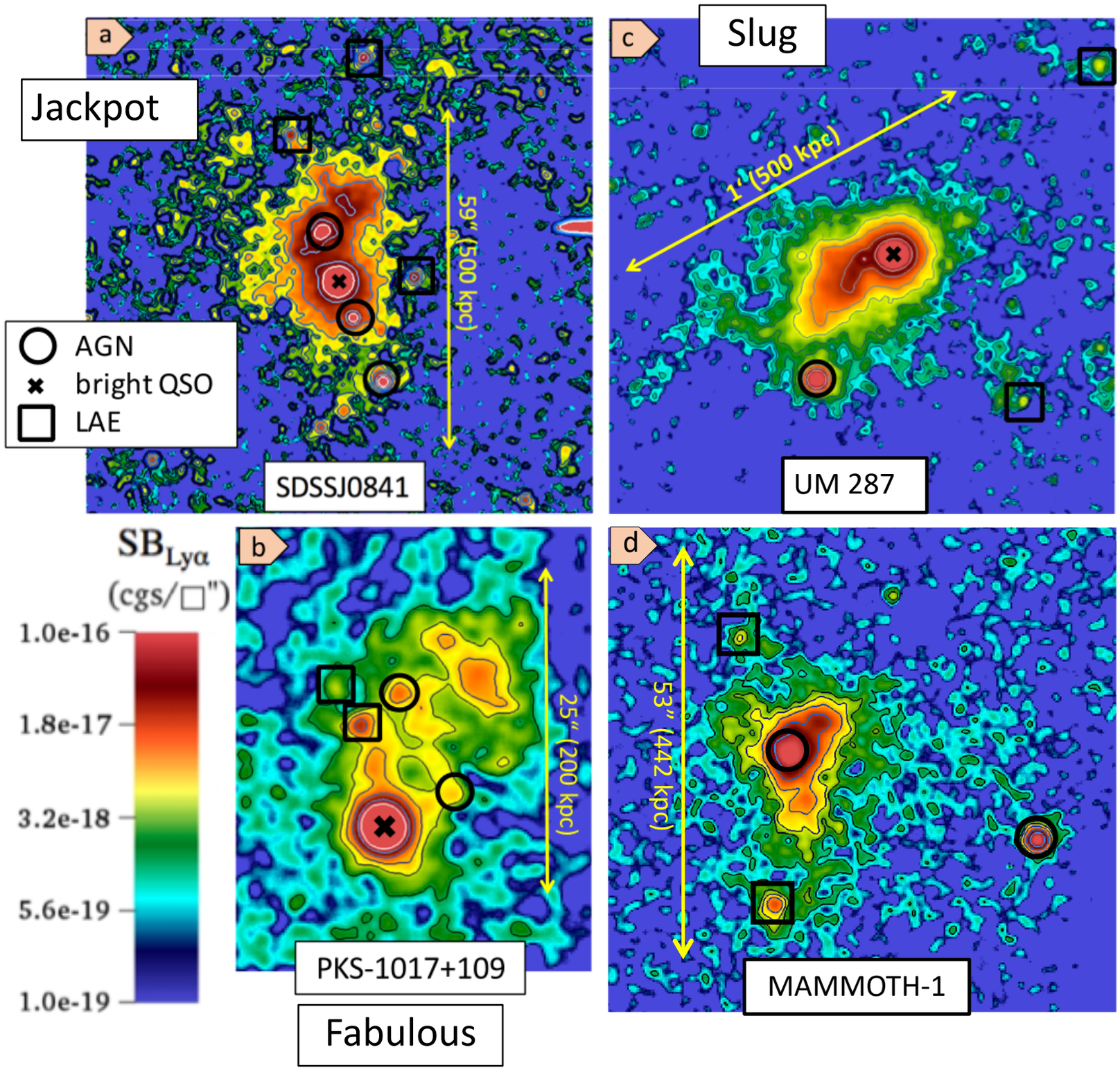
Chiang et al. 2017

QSO sample [QSO-MUSEUM]

Quasars hosting Lyα Nebula uncovered by MUSE

FAB et al. 2018

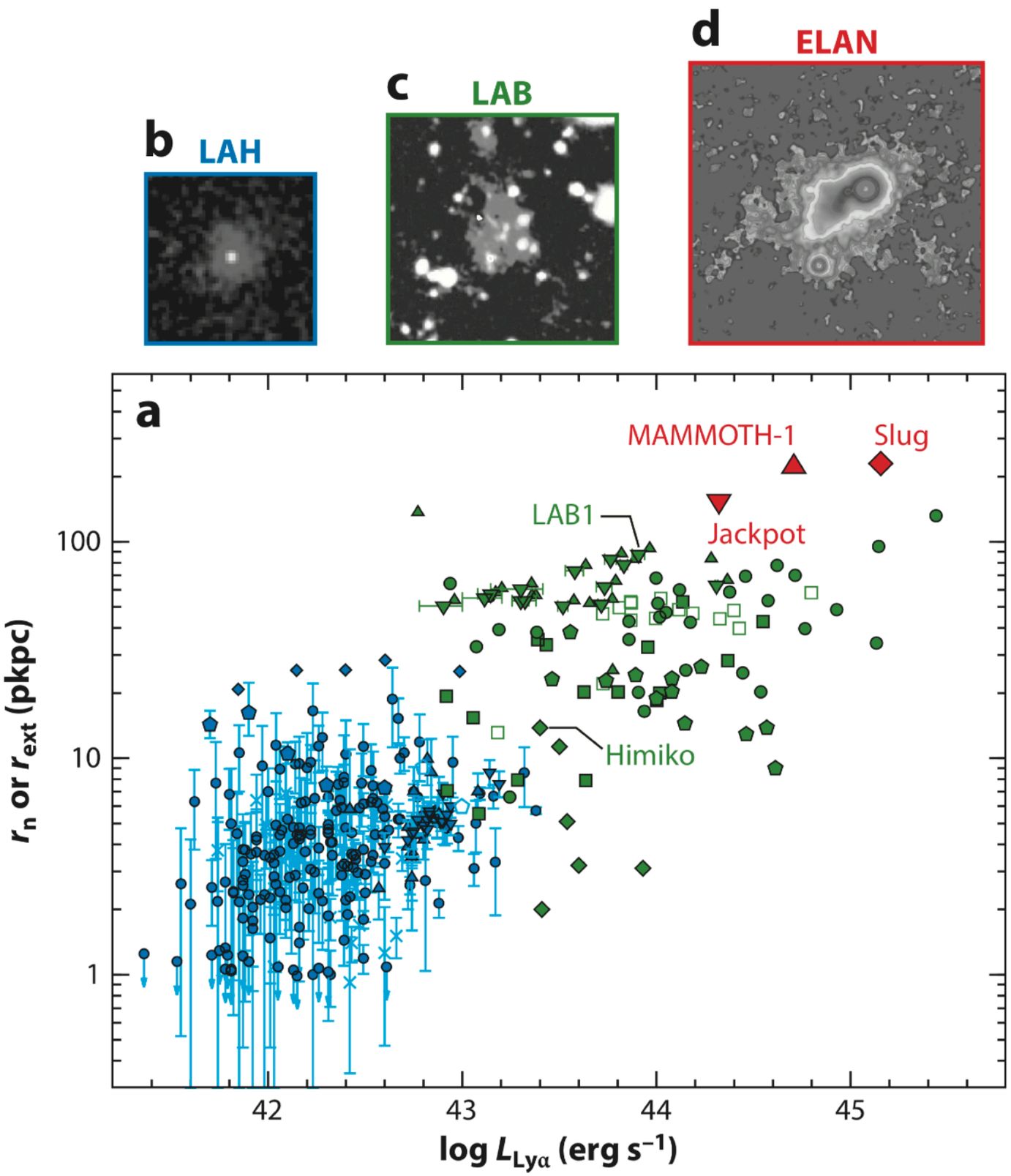
ELAN : Enormous Lyα Nebula



- Discovered with narrow-band and VLT/MUSE
- $2 < z < 3.2$
- Only ~5 % of relatively bright quasars ($M_i < 24$) show such nebulae
- Together with the brightness and the physical extend of Lyα, evidence suggest a large amount (10^{10}-10^{11} solar masses) of cool ($T \sim 10^4$K) and clumpy (C~100) gas.

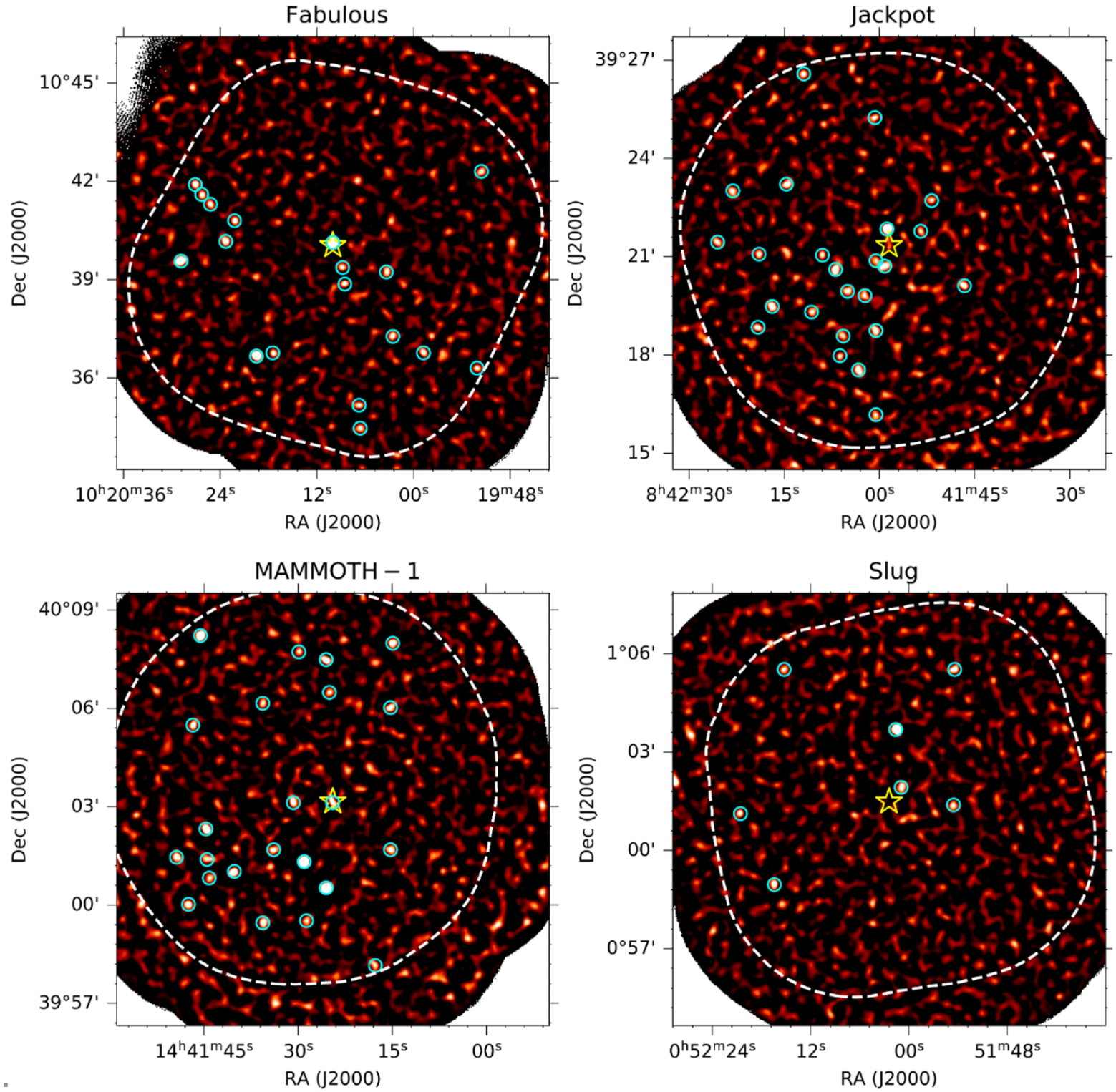
Cantalupo+2014, Hennawi+2015, Cai+2017, FAB+2018

Classes of Lyα Nebula



Ouchi+2020

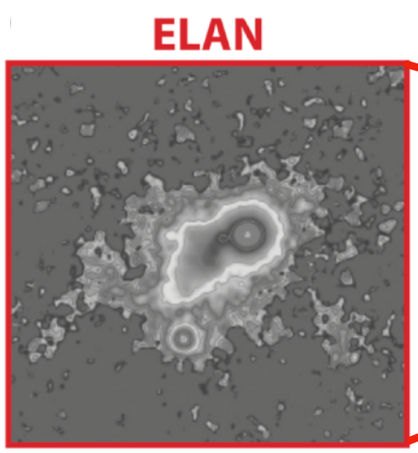
SCUBA-2 850 micron observations

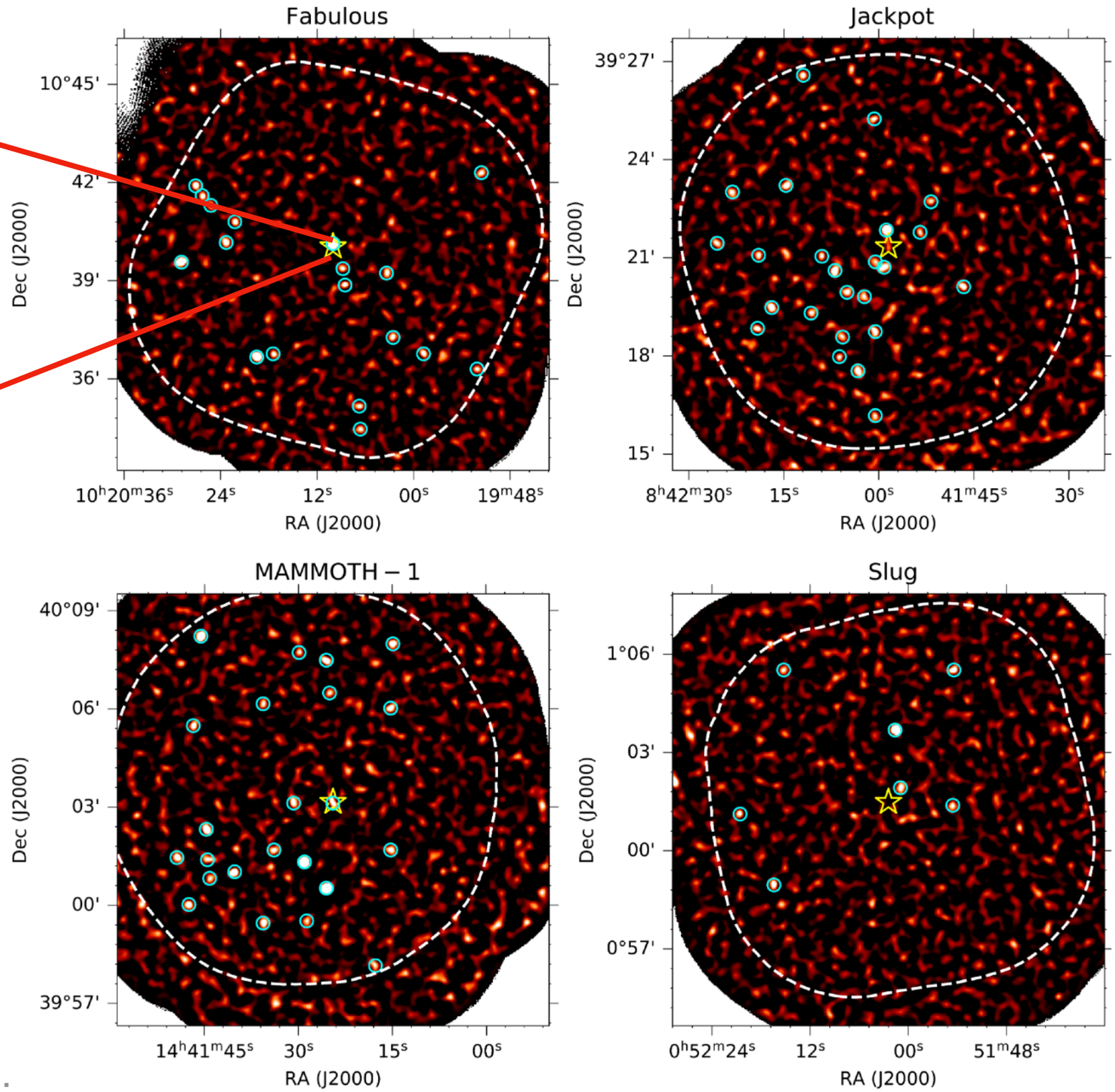


FAB, CCC, et al. 2018;
Nowotka, CCC, FAB, et al. 2022

~1 mJy/beam r.m.s. at 850 micron

SCUBA-2 850 micron observations





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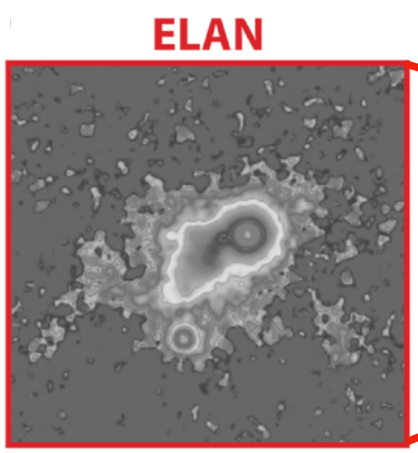

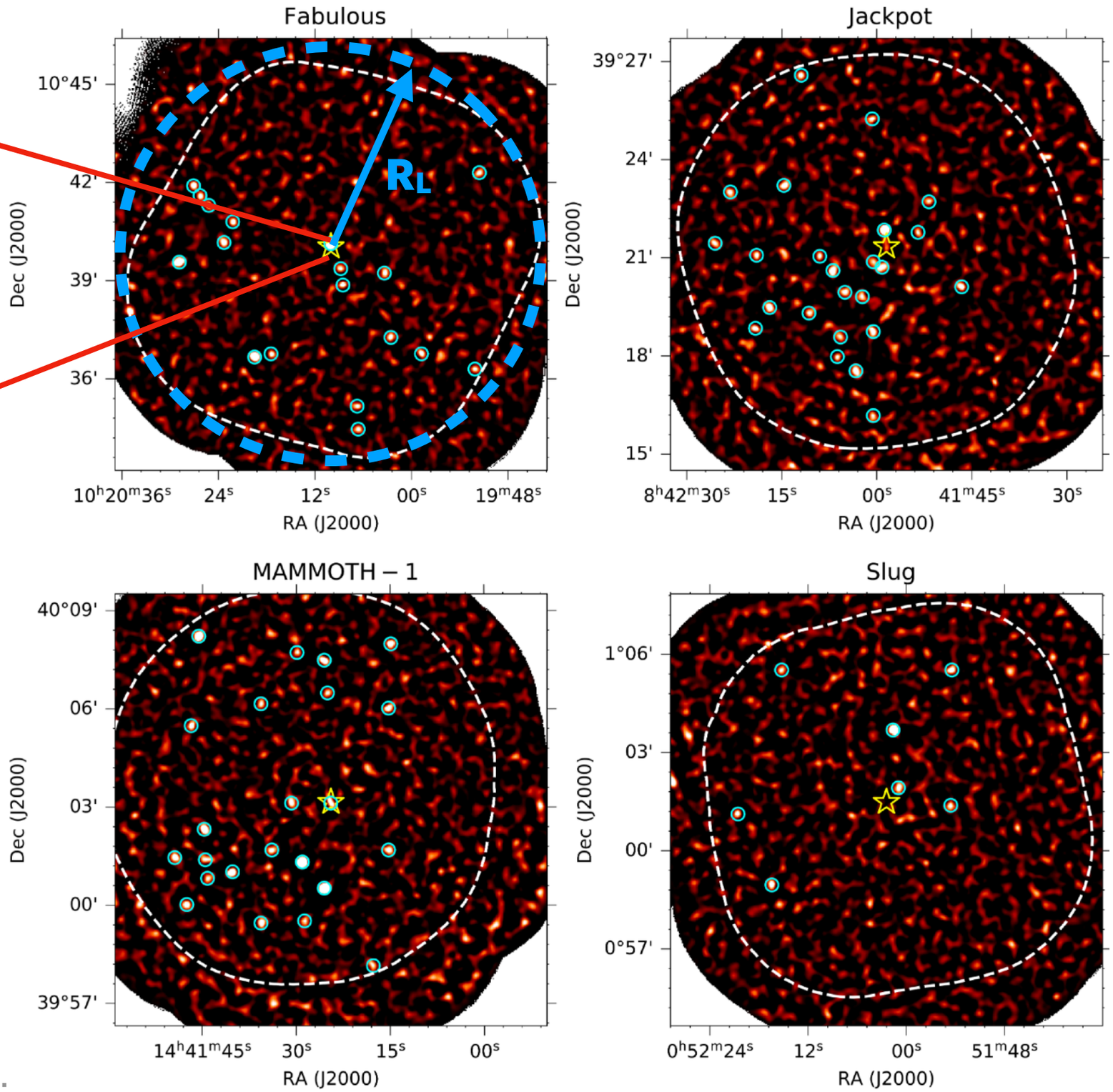

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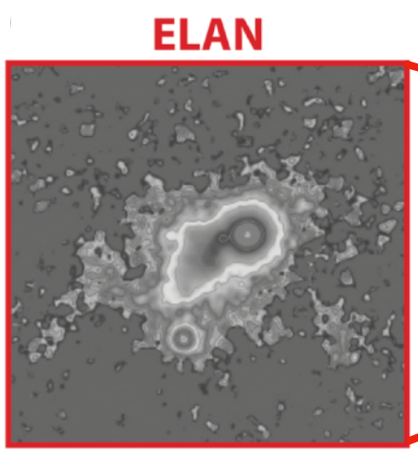

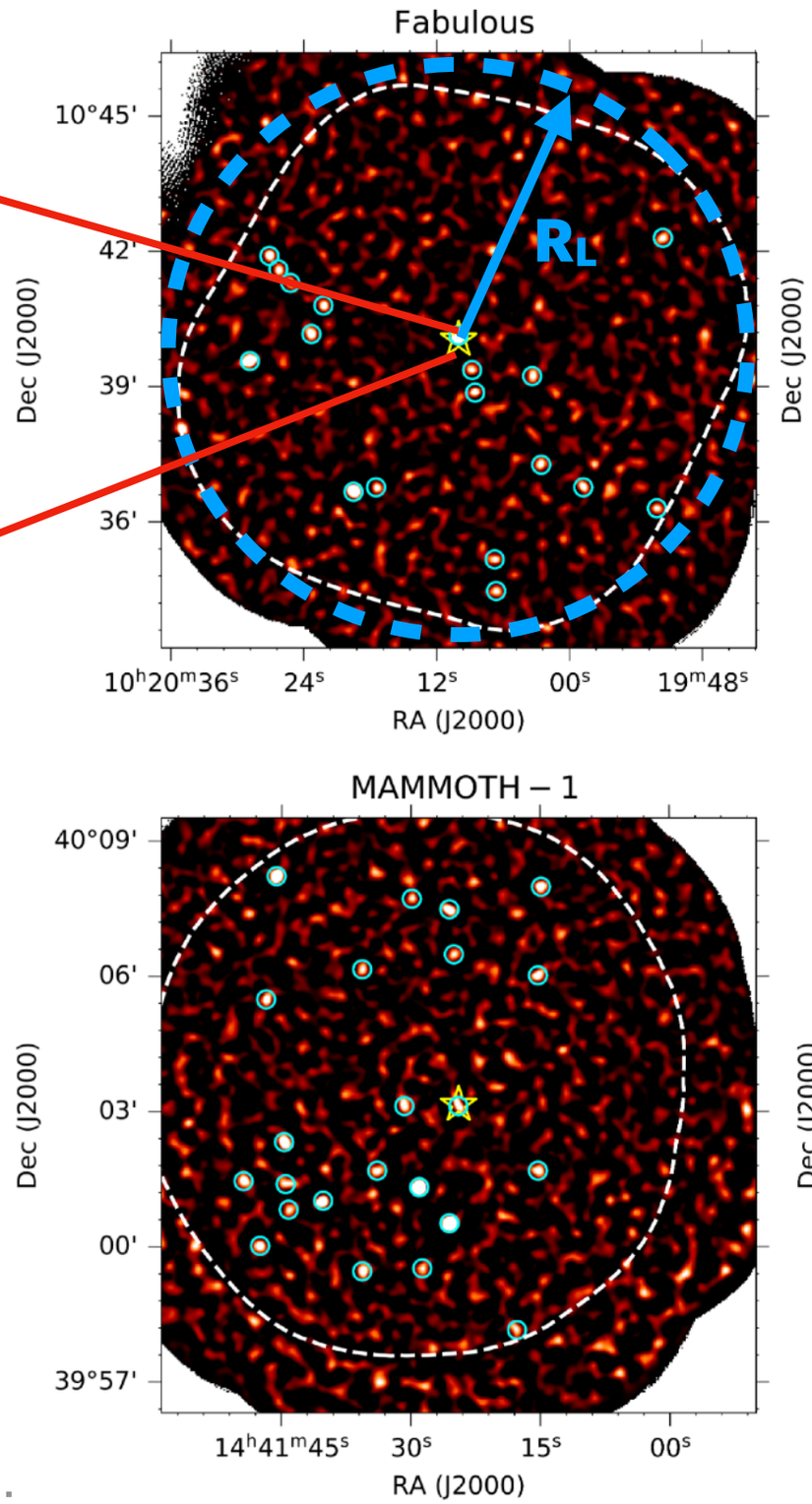

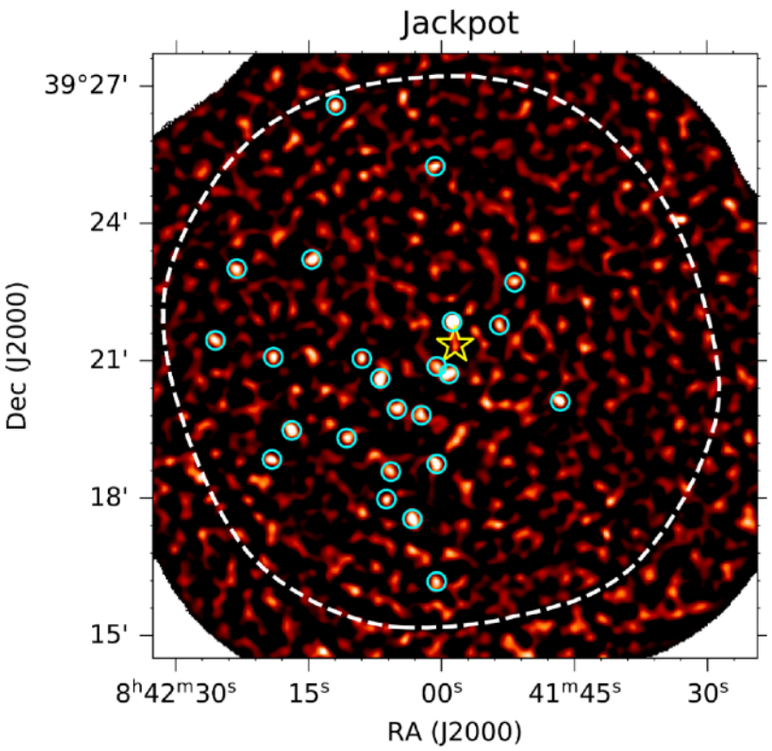

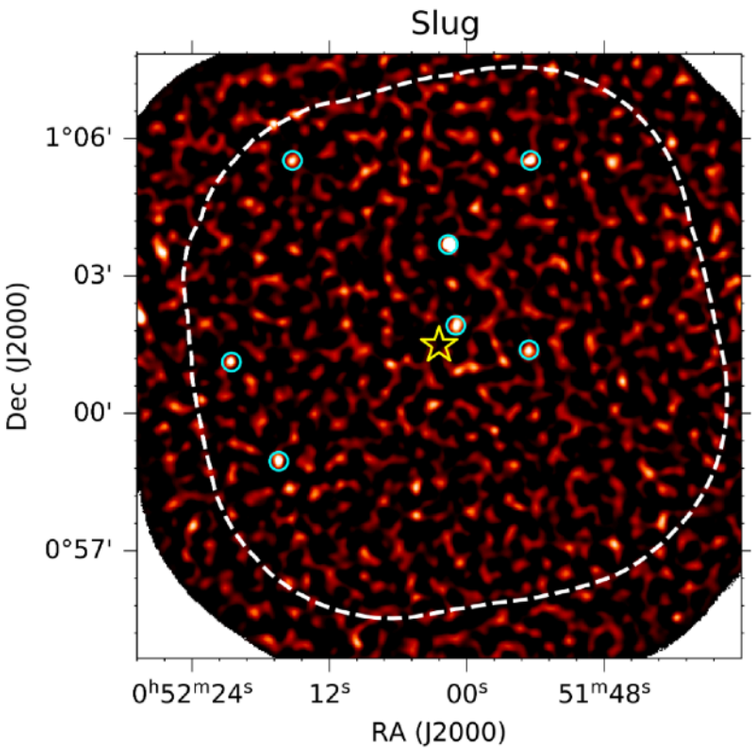

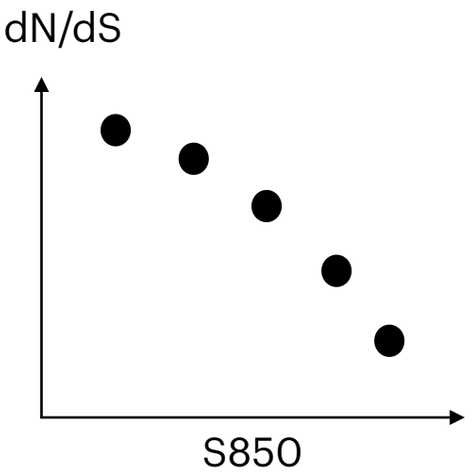

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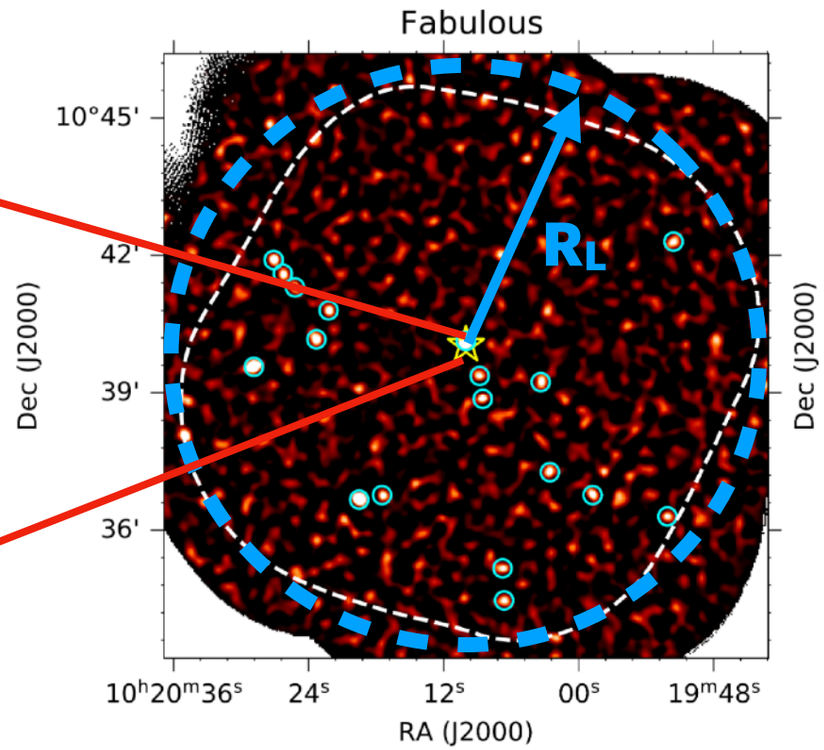

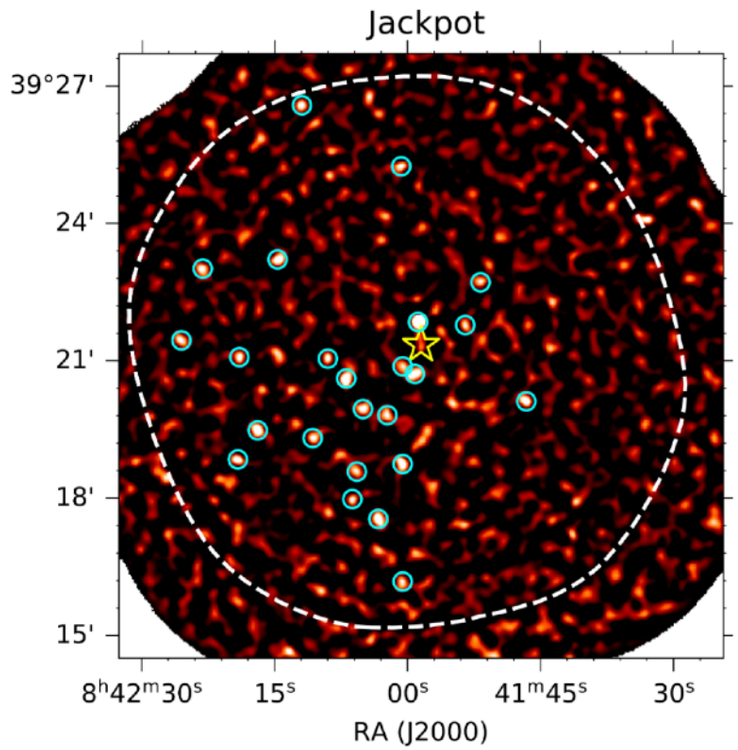

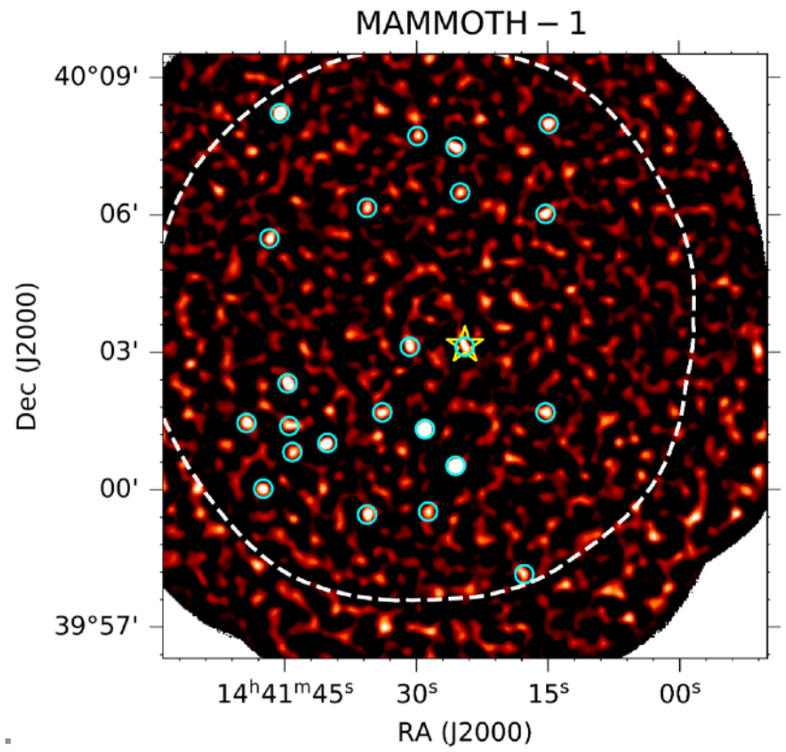

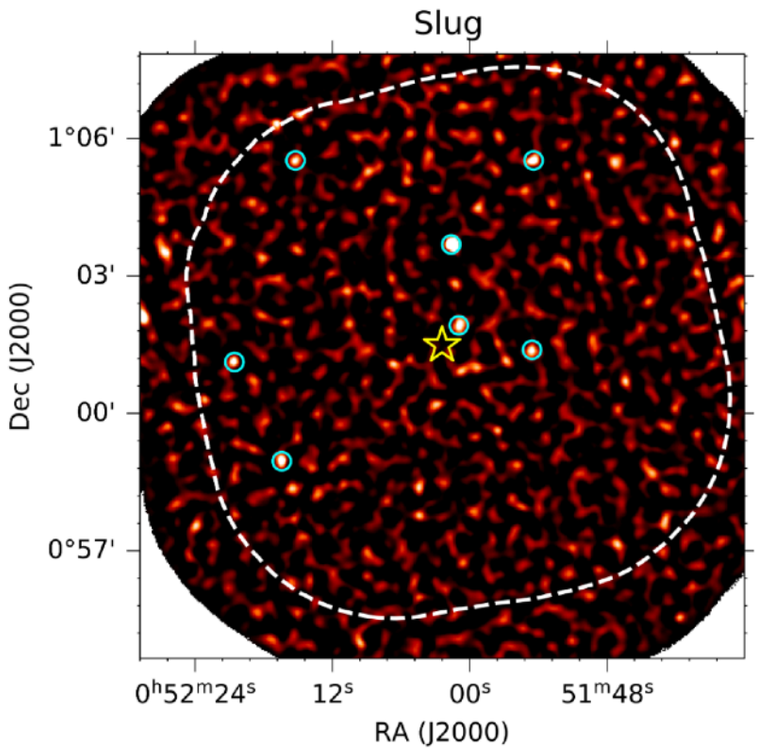

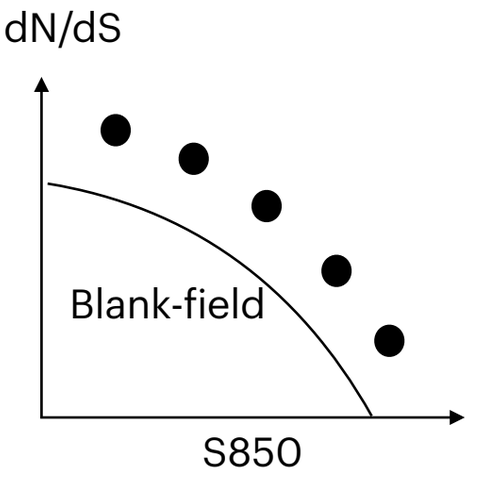

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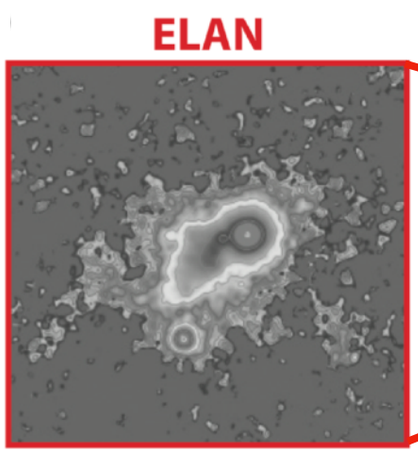
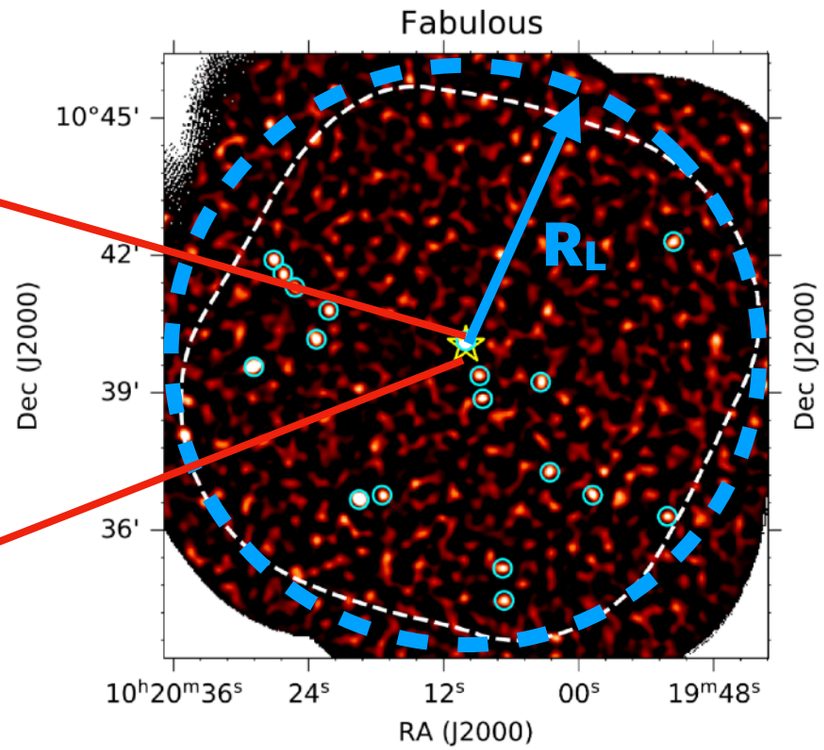
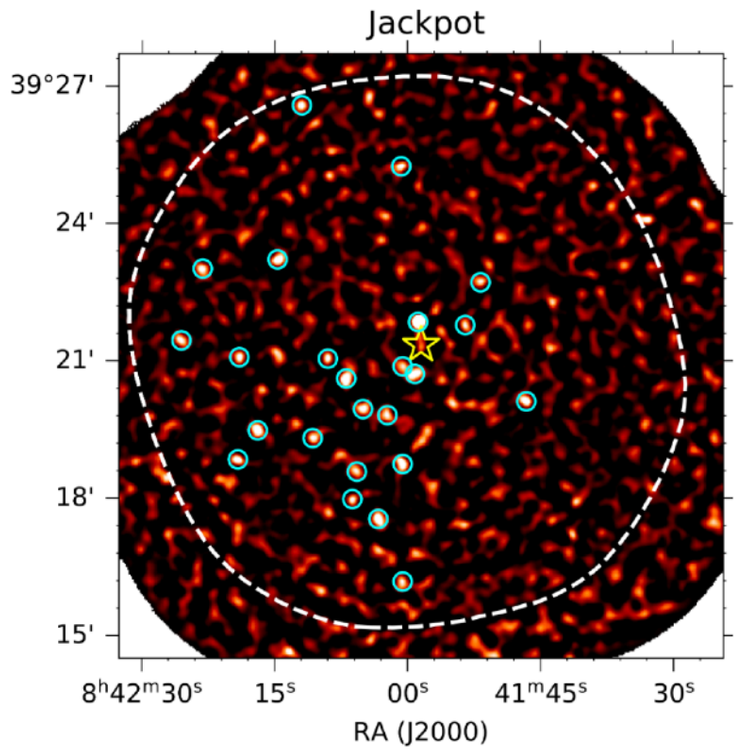
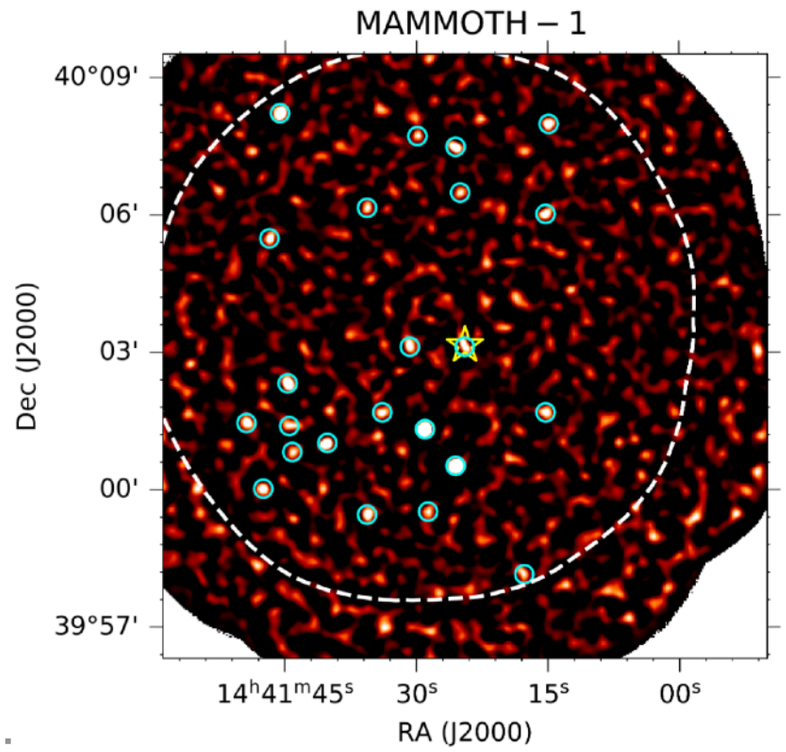
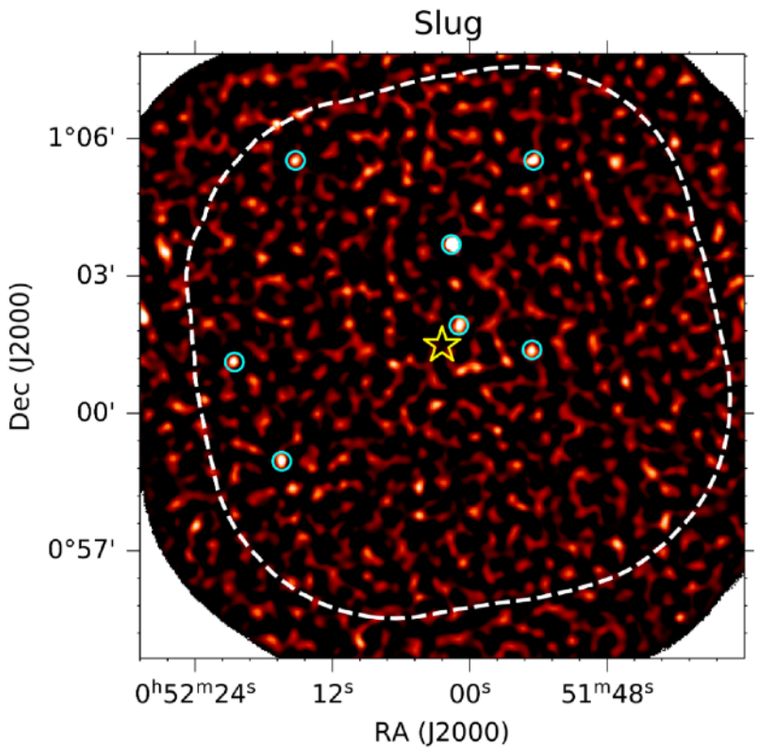
SCUBA-2 850 micron observations

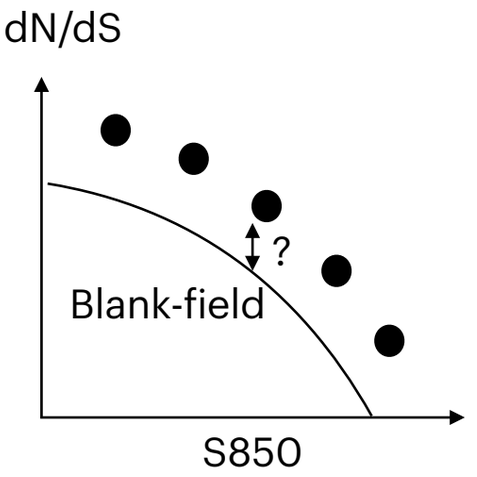












FAB, CCC, et al. 2018;
Nowotka, CCC, FAB, et al. 2022

~1 mJy/beam r.m.s. at 850 micron

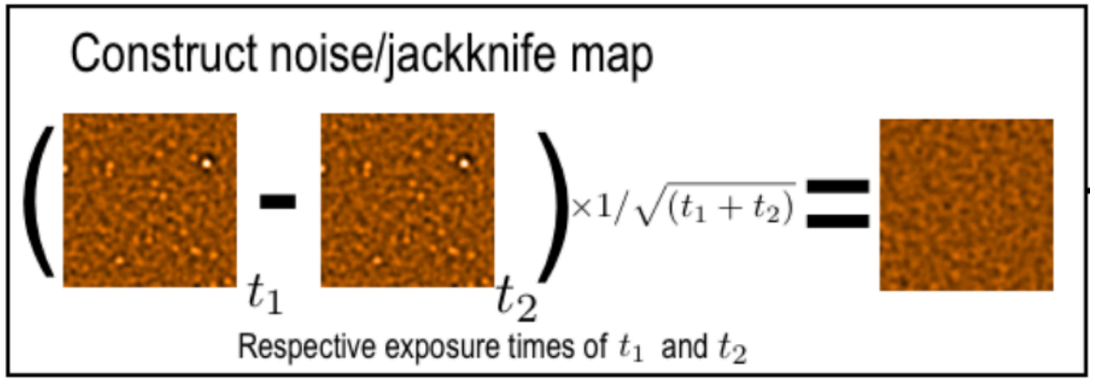
Number counts analyses

Methodology - making mock images with models to account for various effects

Casey et al. 2014

Number counts analyses

Methodology - making mock images with models to account for various effects

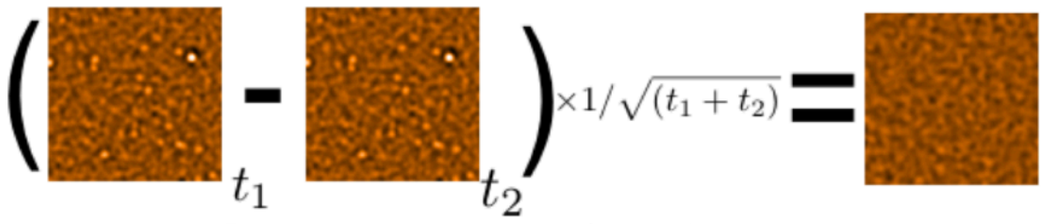


Casey et al. 2014

Number counts analyses

Methodology - making mock images with models to account for various effects

Construct noise/jackknife map



Respective exposure times of t_1 and t_2

Inject sources drawn from dN/dS into jackknife map, for example:

$$\frac{dN}{dS} = \begin{cases} \frac{N_0}{S_0}(\frac{S}{S_0})^{-\alpha} & : S \leq S_0 \\ \frac{N_0}{S_0}(\frac{S}{S_0})^{-\beta} & : S > S_0 \end{cases}$$

Choose best-guess N_0, S_0, α, β

Randomize source positions, convolve with beam.

Casey et al. 2014

Number counts analyses

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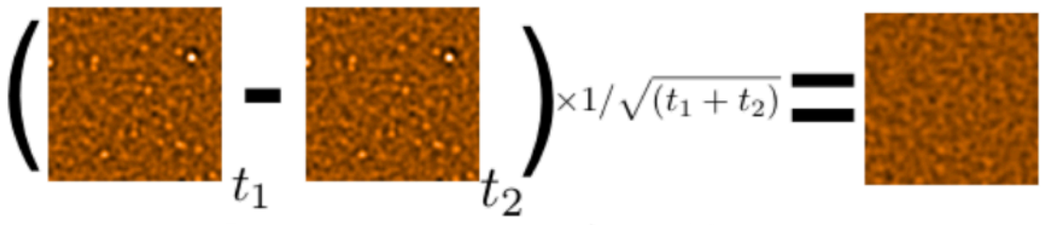
Construct noise/jackknife map



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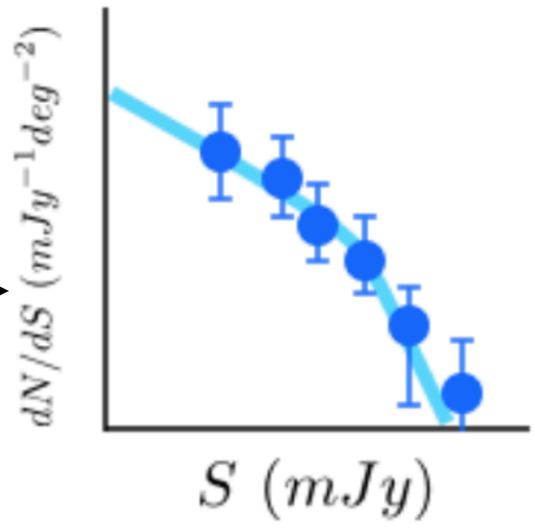
Choose best-guess N_0, S_0, α, β

Randomize source positions, convolve with beam.

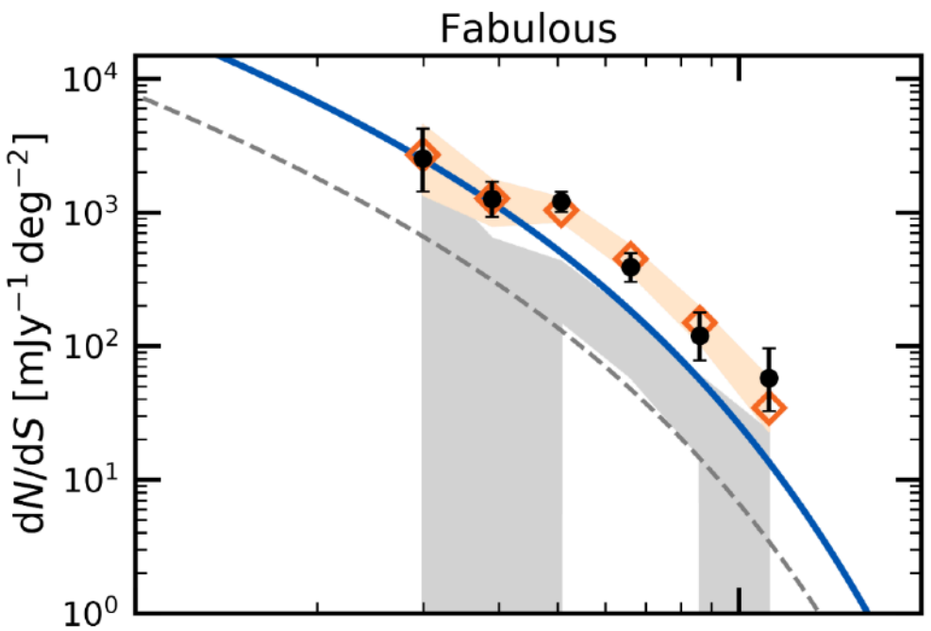
Measure dN/dS, compare sims maps to real map dN/dS



Alter choice of N_0, S_0, α, β until best agreement with real dN/dS is found (e.g. Markov Chain method)

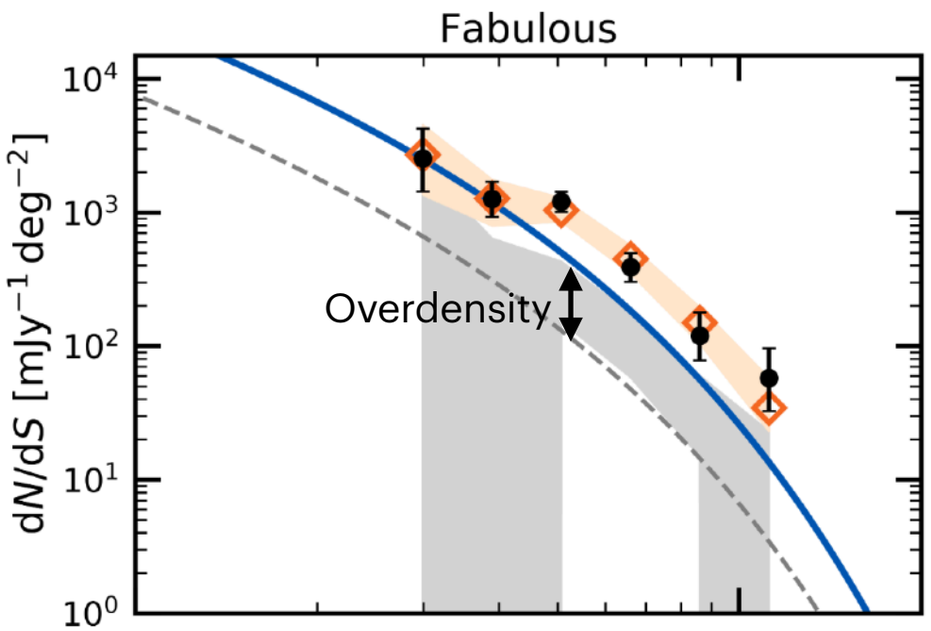
Casey et al. 2014

Results - number counts



Nowotka, CCC, FAB, et al. 2022

Results - number counts



Nowotka, CCC, FAB, et al. 2022

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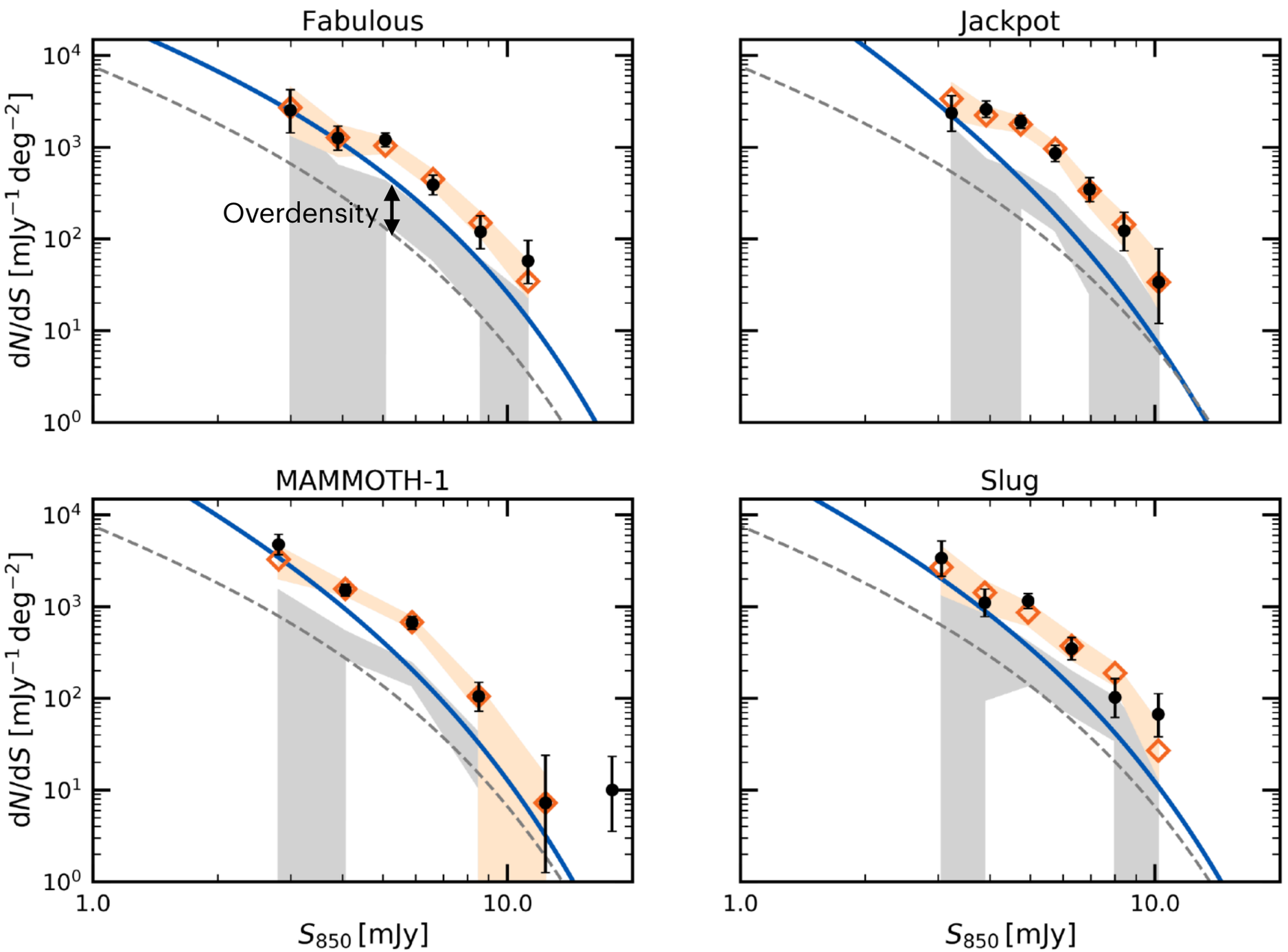
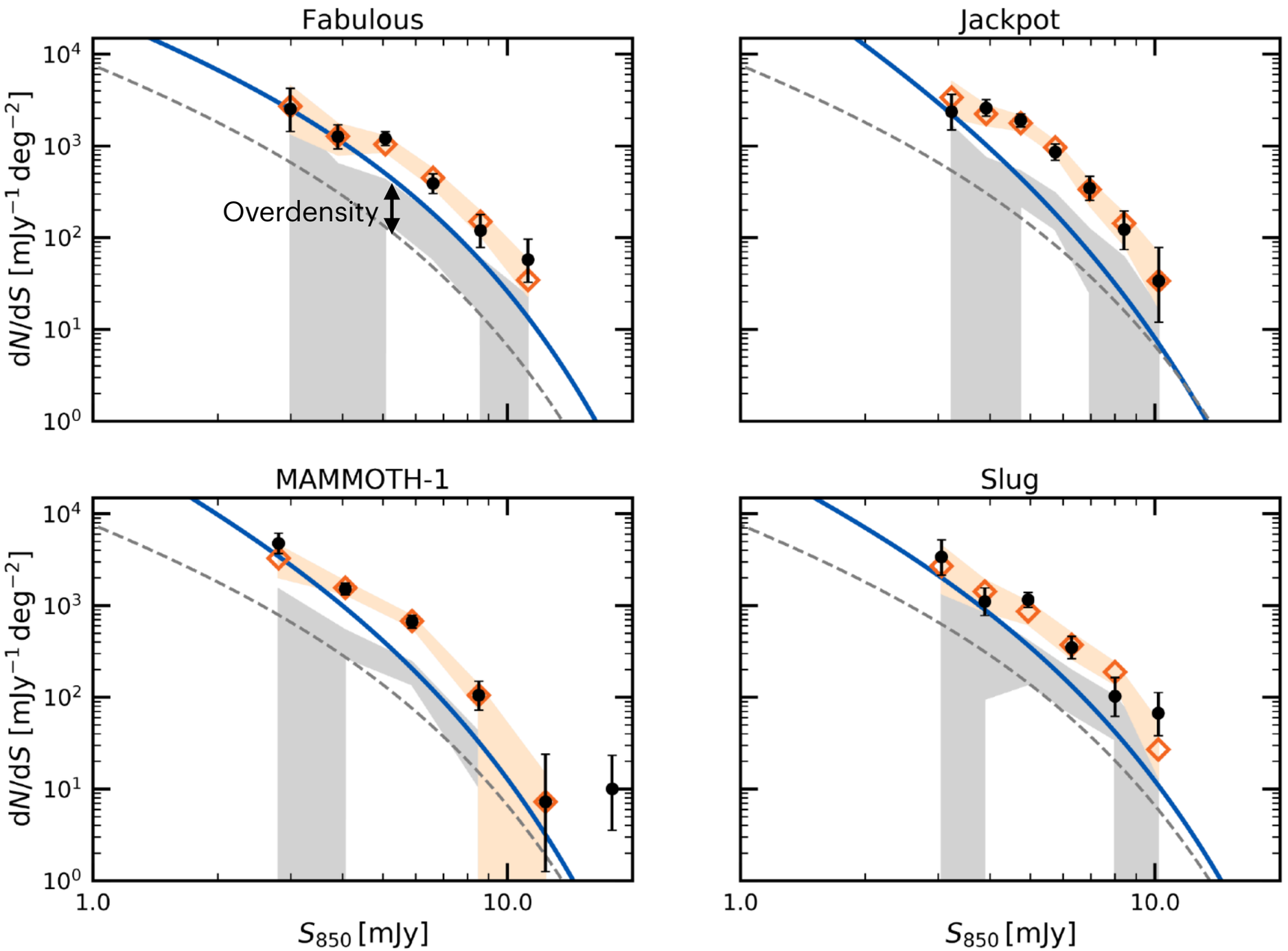


Nowotka, CCC, FAB, et al. 2022

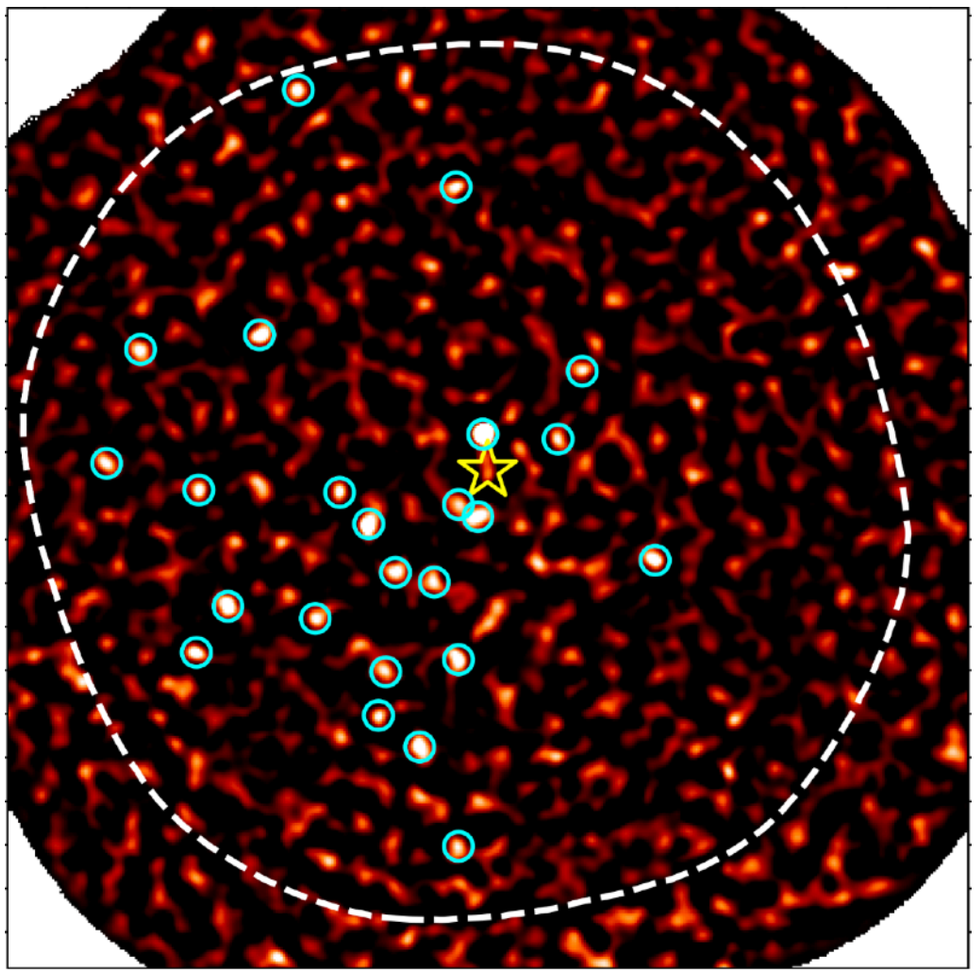
Results - number counts

Over-abundance in all four ELAN fields, by a factor of ~2-4



Nowotka, CCC, FAB, et al. 2022

Integrated SFR density



Nowotka, CCC, FAB, et al. 2022

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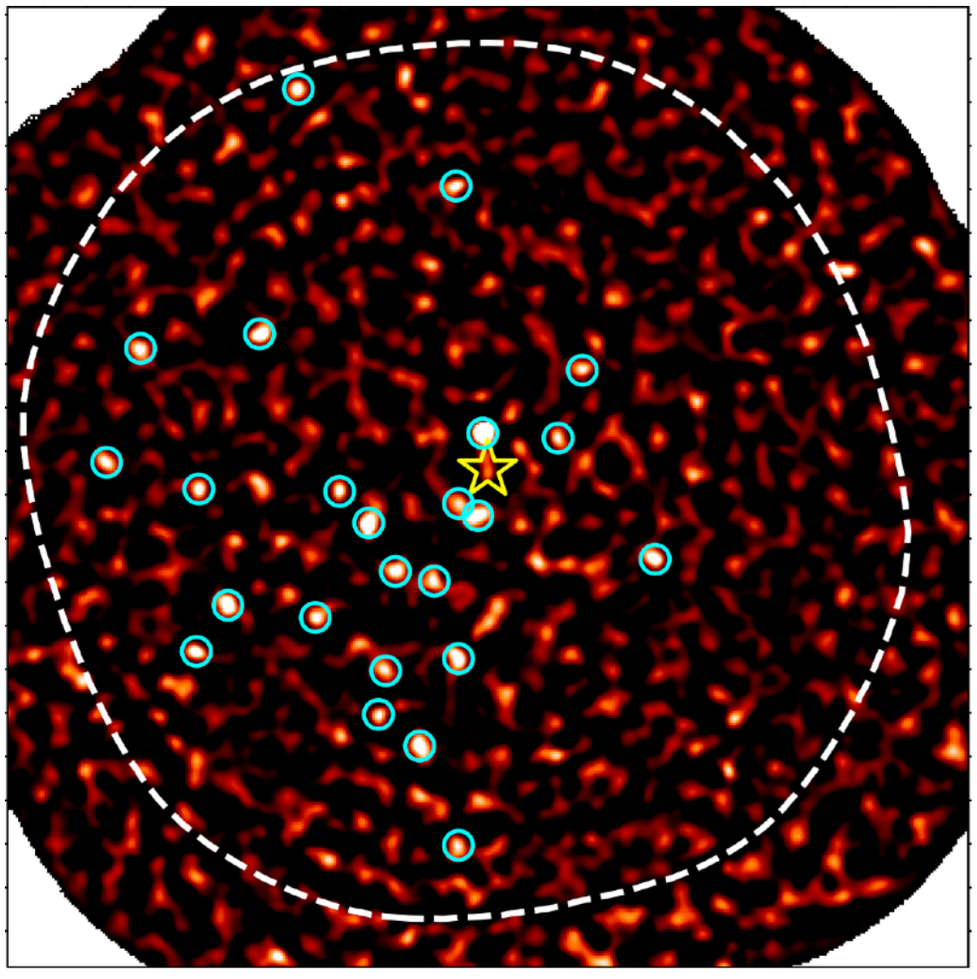
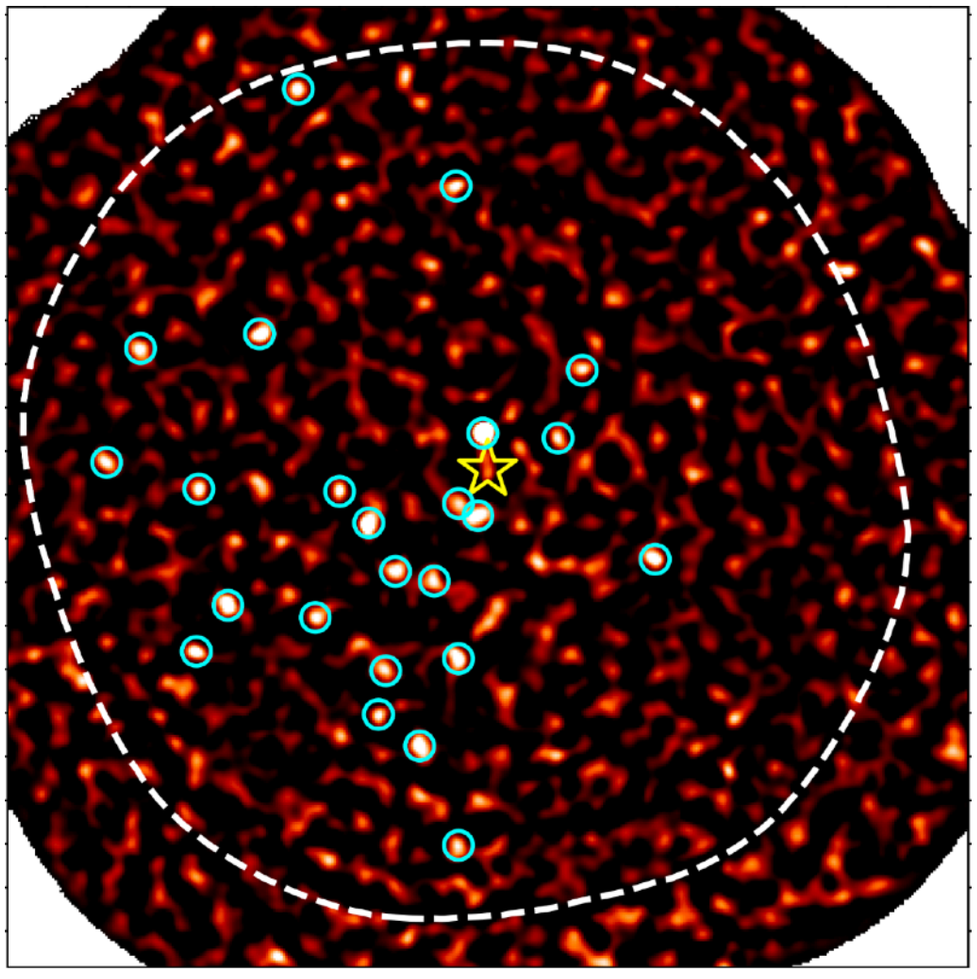


- Assuming all sources in excess of the field counts are associated with the central systems

Nowotka, CCC, FAB, et al. 2022

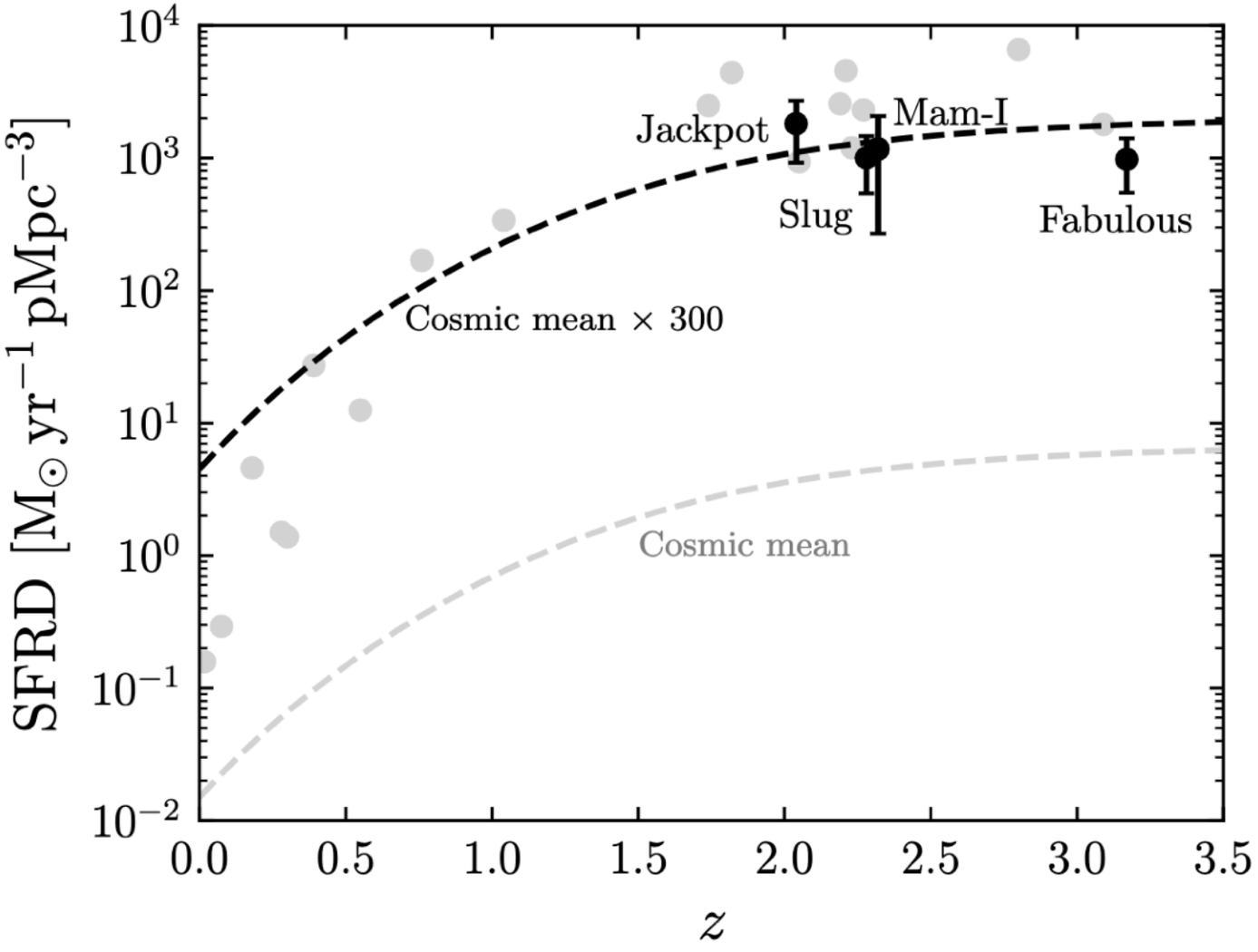
Integrated SFR density



- Assuming all sources in excess of the field counts are associated with the central systems
- Apply a conversion between S850 and SFR

Nowotka, CCC, FAB, et al. 2022

Integrated SFR density

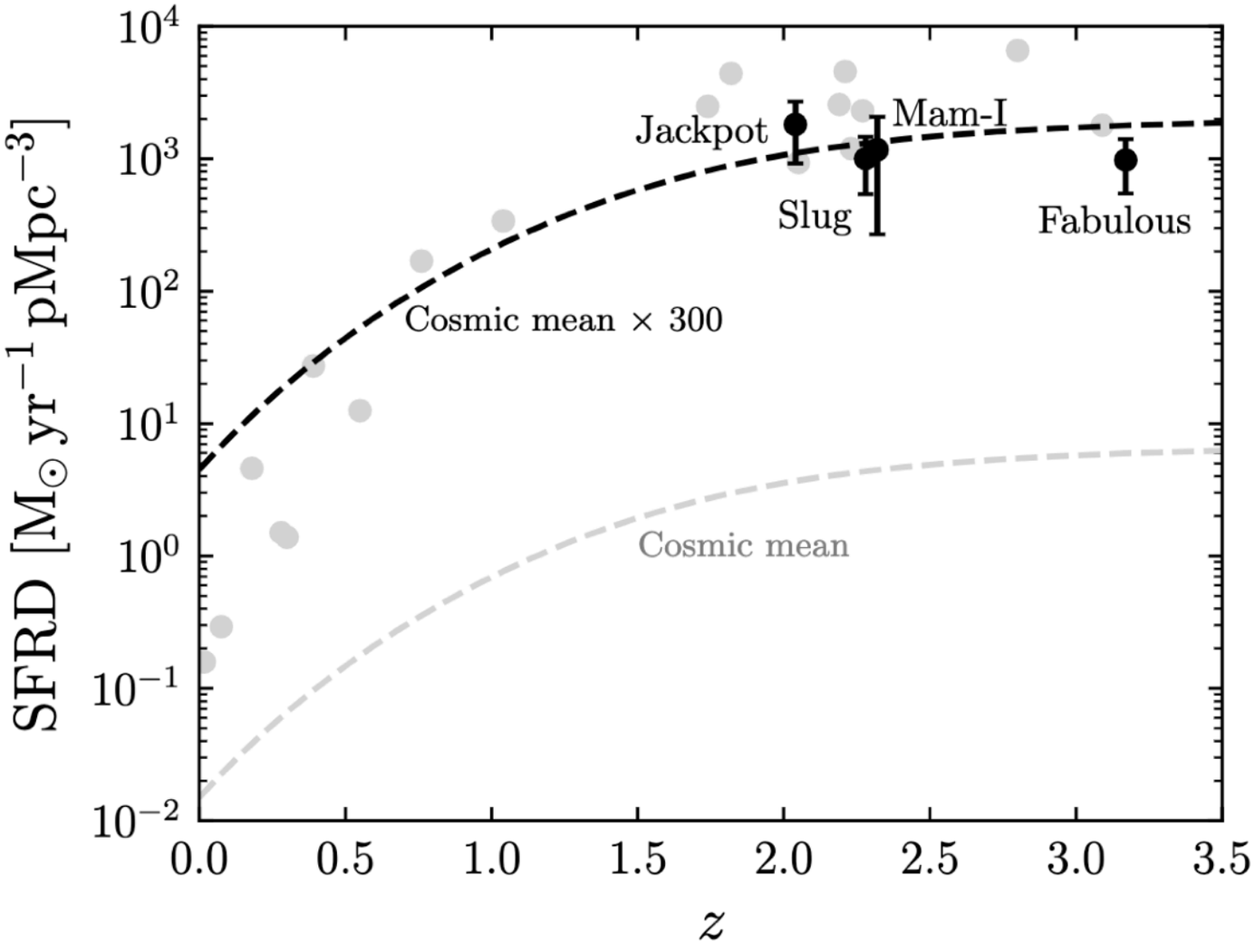


- Assuming all sources in excess of the field counts are associated with the central systems
- Apply a conversion between S850 and SFR

Nowotka, CCC, FAB, et al. 2022

Integrated SFR density

~300 times the cosmic mean and comparable to what model predicts



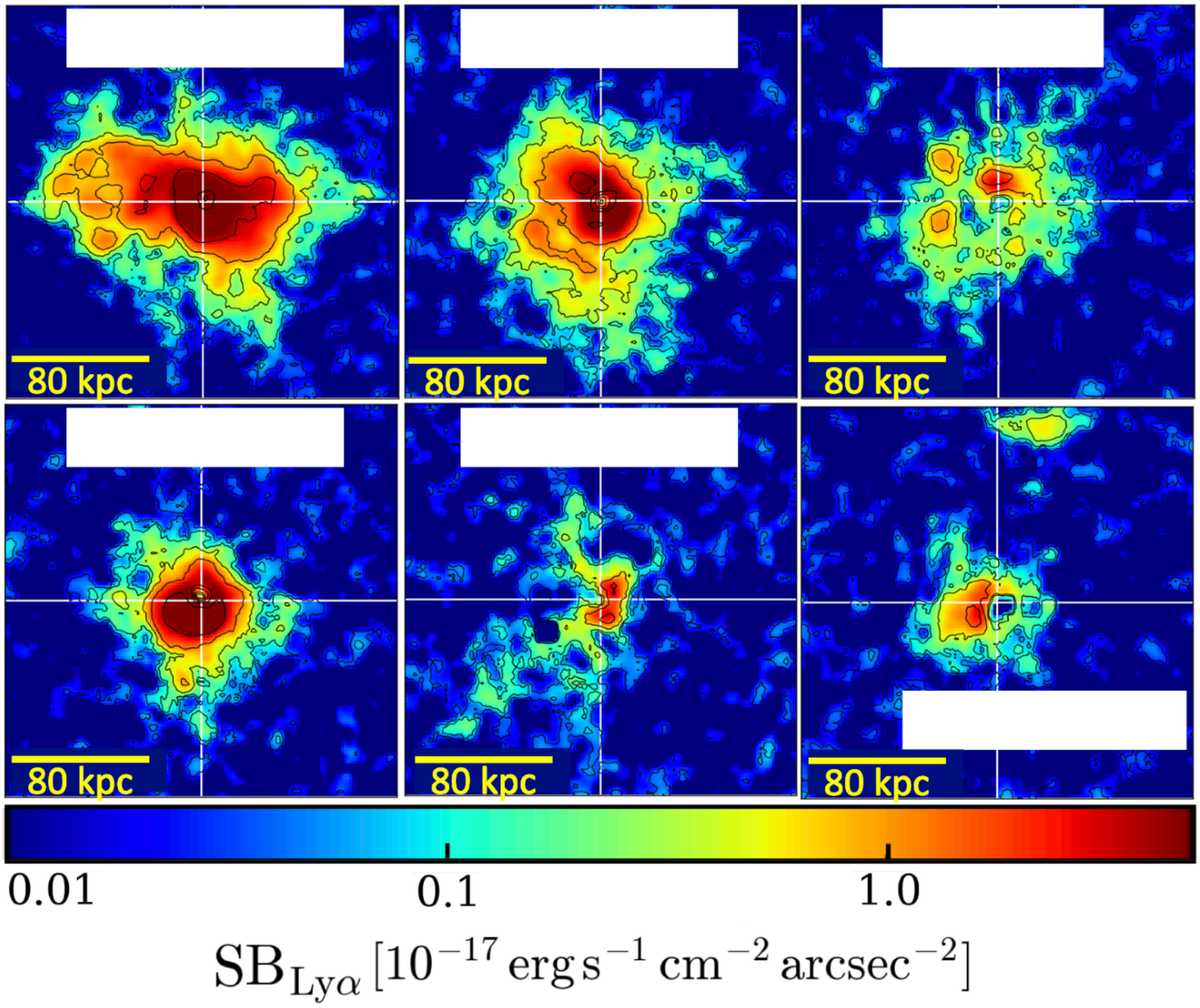
- Assuming all sources in excess of the field counts are associated with the central systems
- Apply a conversion between S850 and SFR

Nowotka, CCC, FAB, et al. 2022

Preliminary

Expanding the survey

QSO with smaller nebula sizes

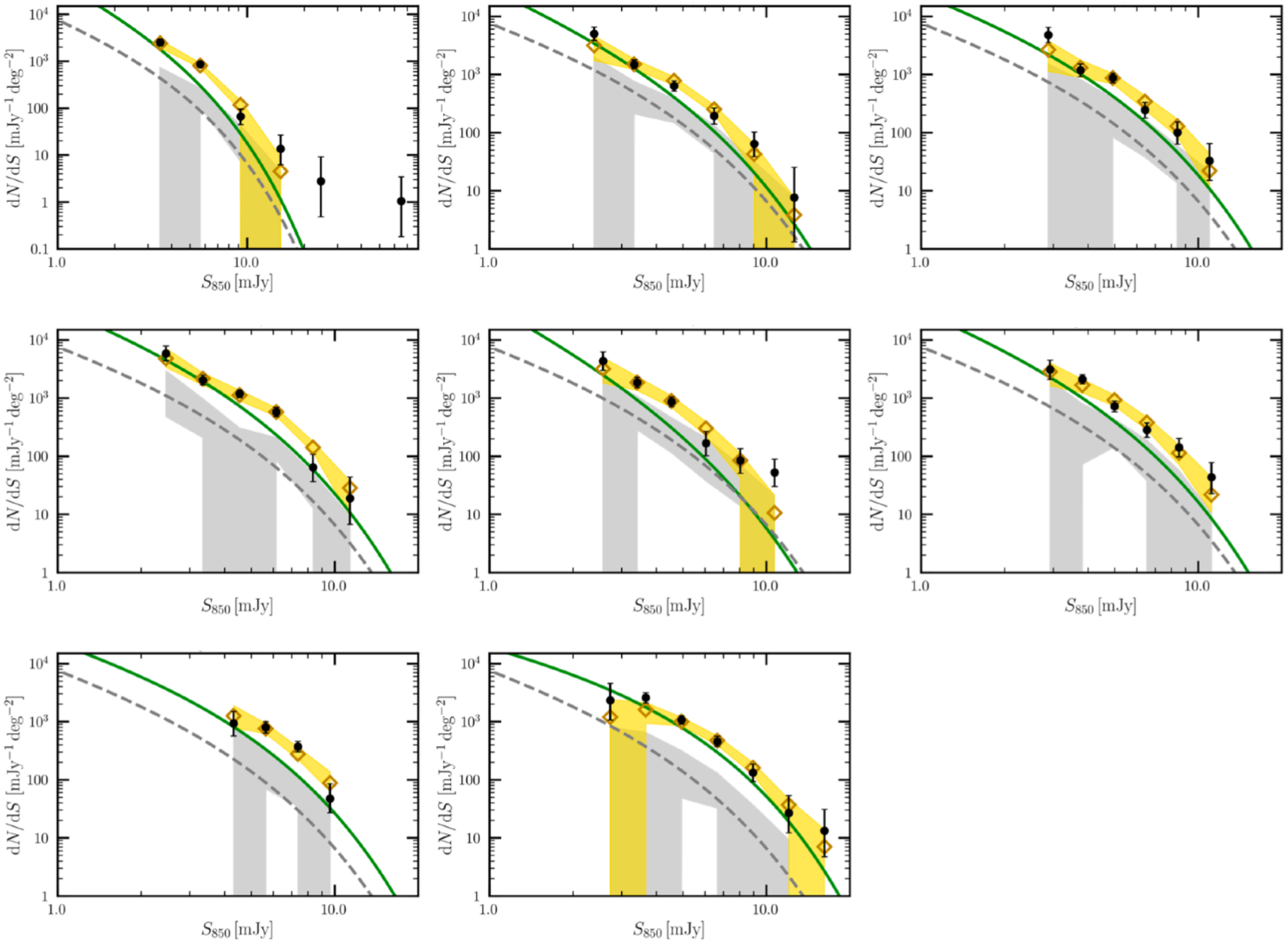


FAB et al. 2018

More counts

Preliminary

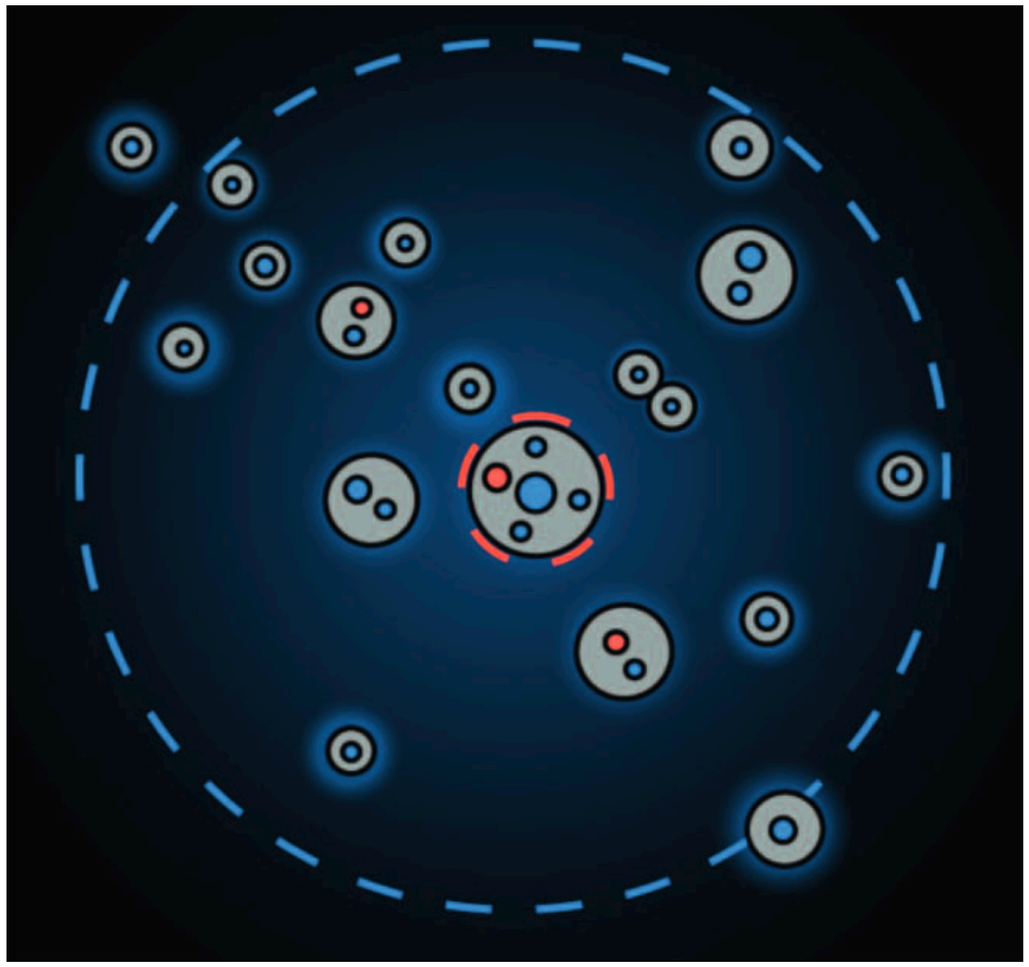
Ubiquitous overdensity,
confirming intimate coevolution between SMGs and QSOs

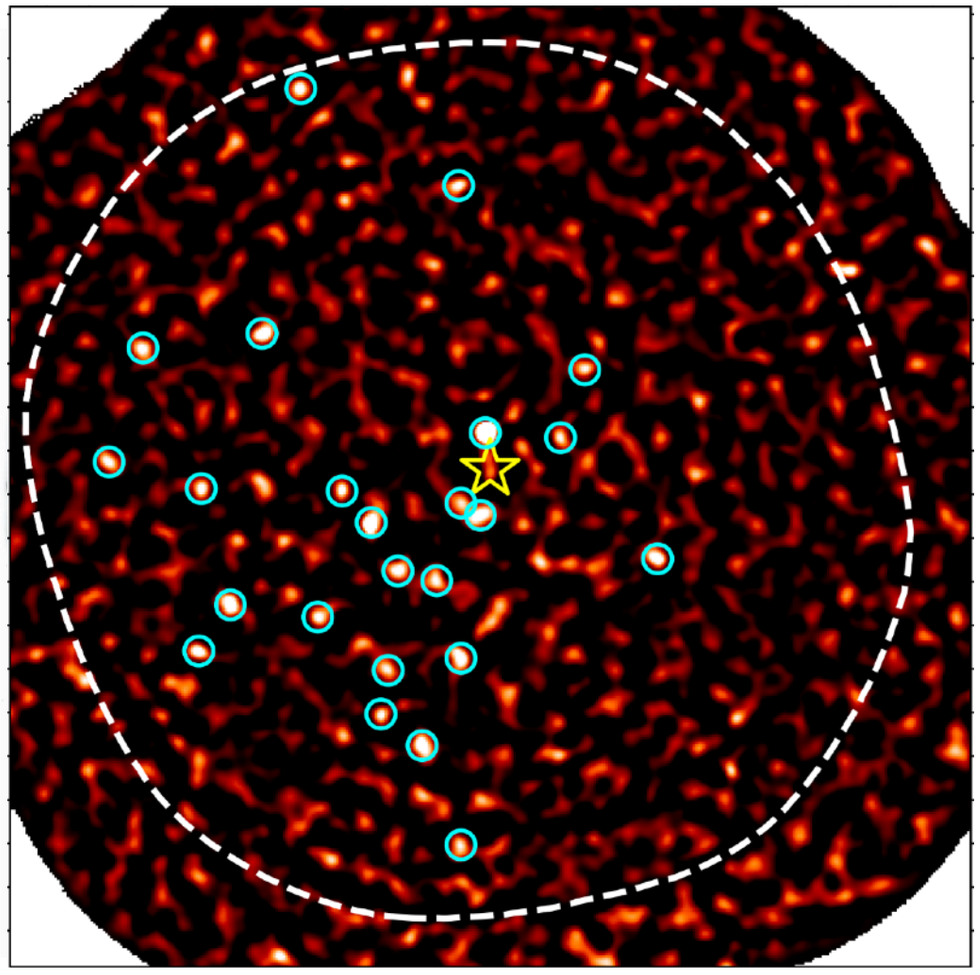


FAB, CCC, Nowotka in prep.

ALMA spectral follow-up

Membership confirmation





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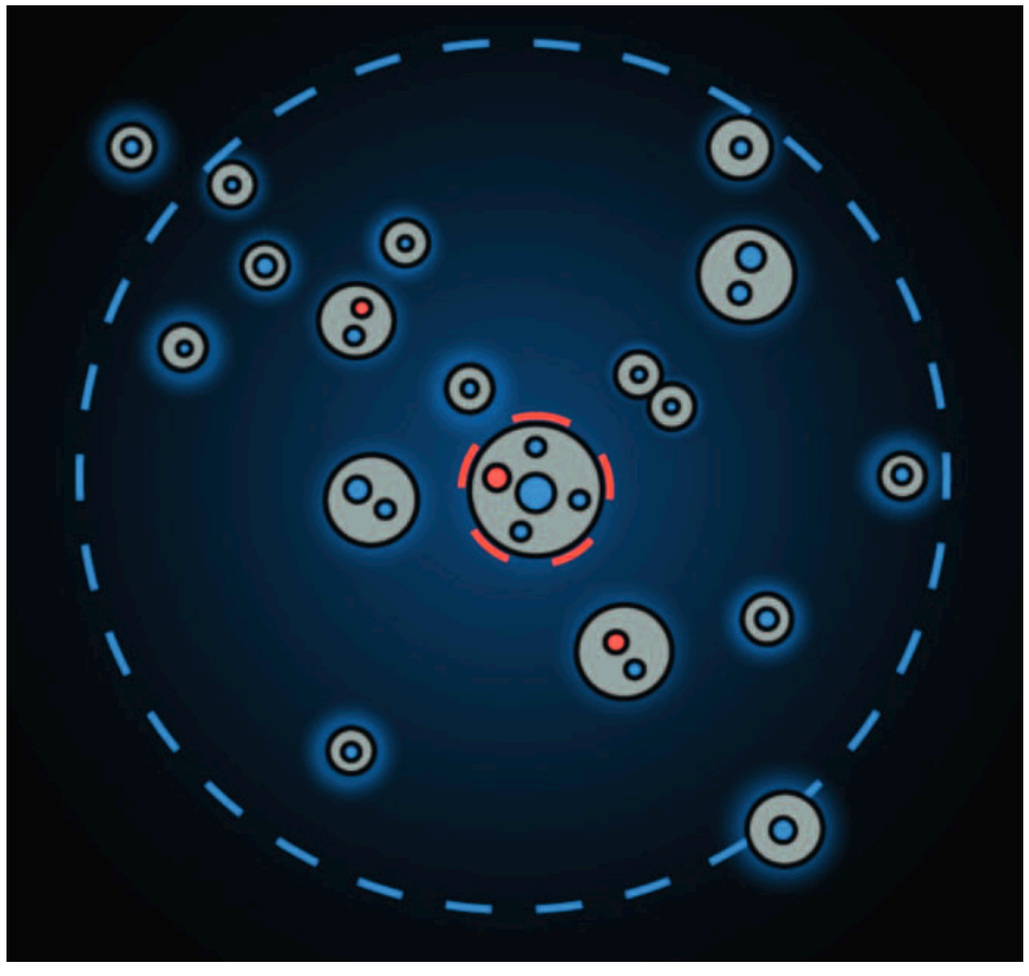

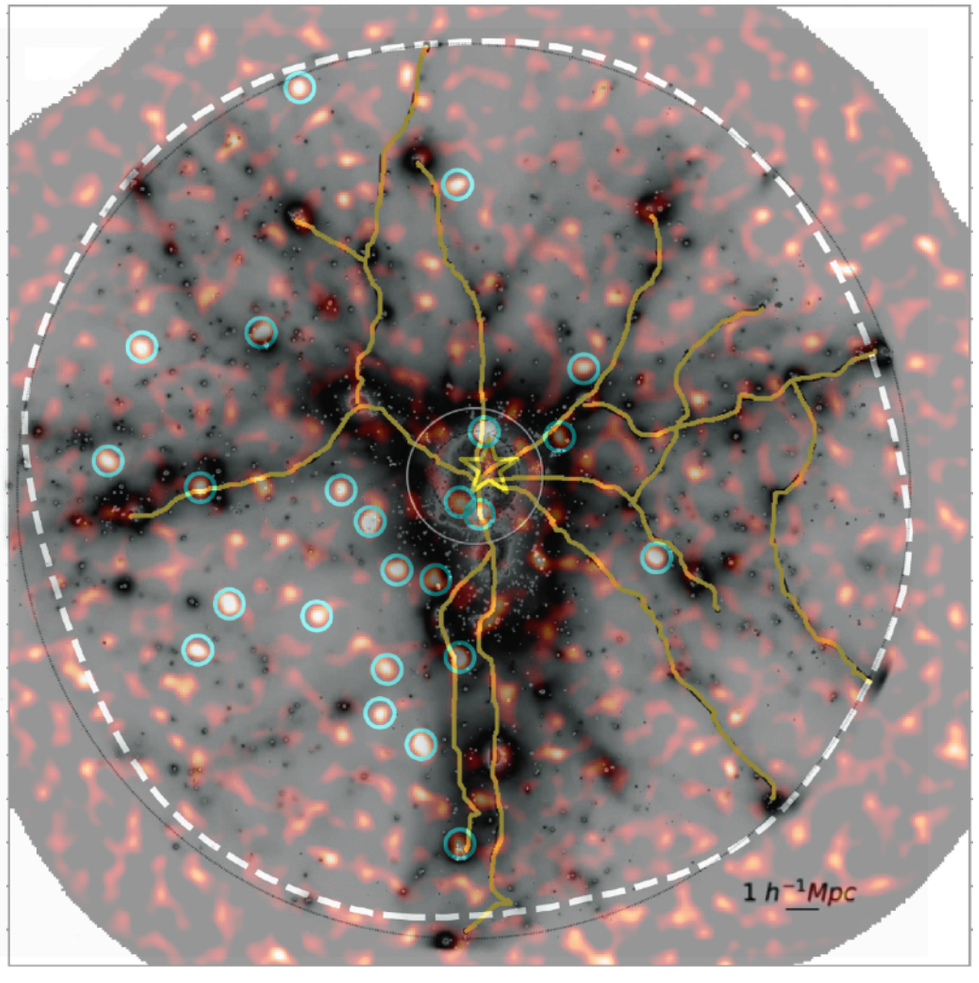

Preliminary

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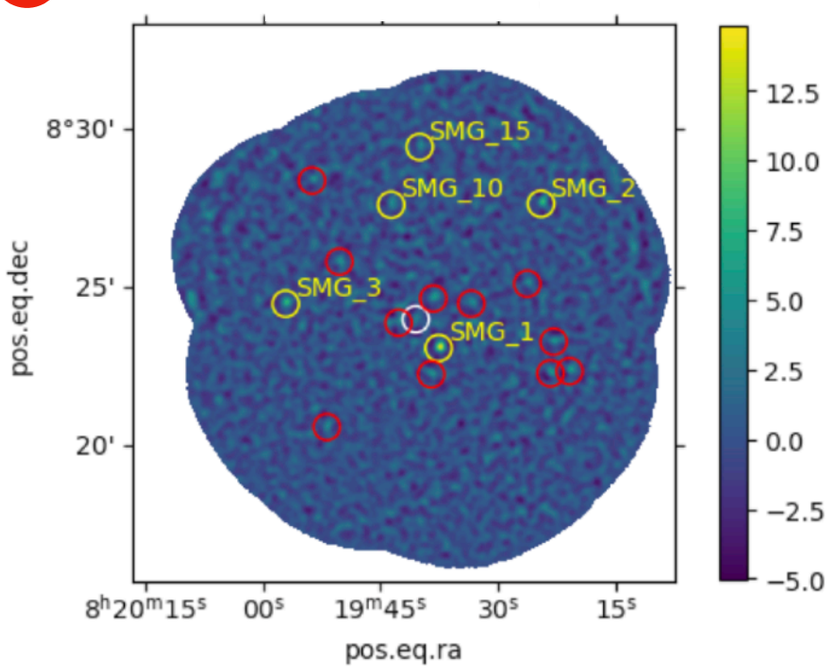
Membership confirmation

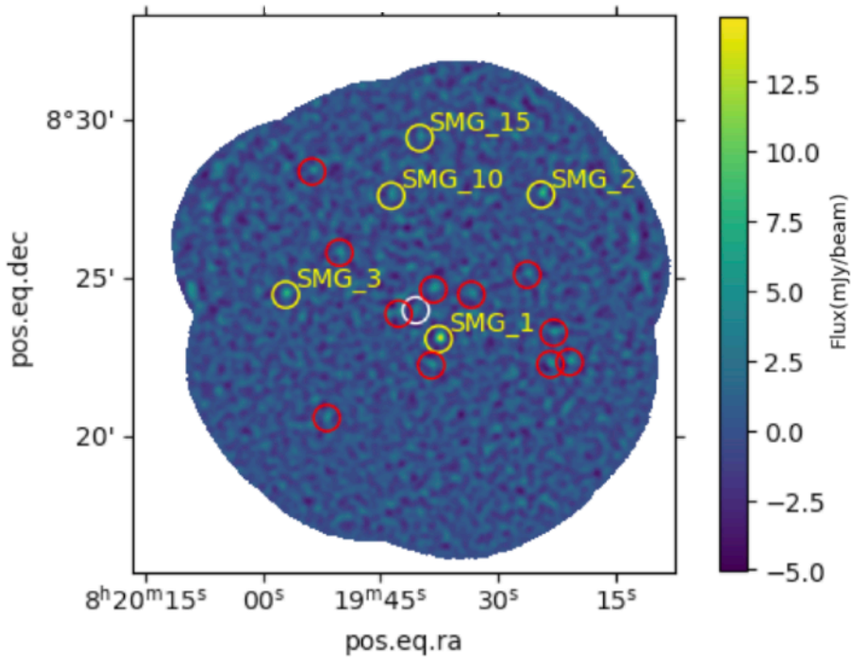


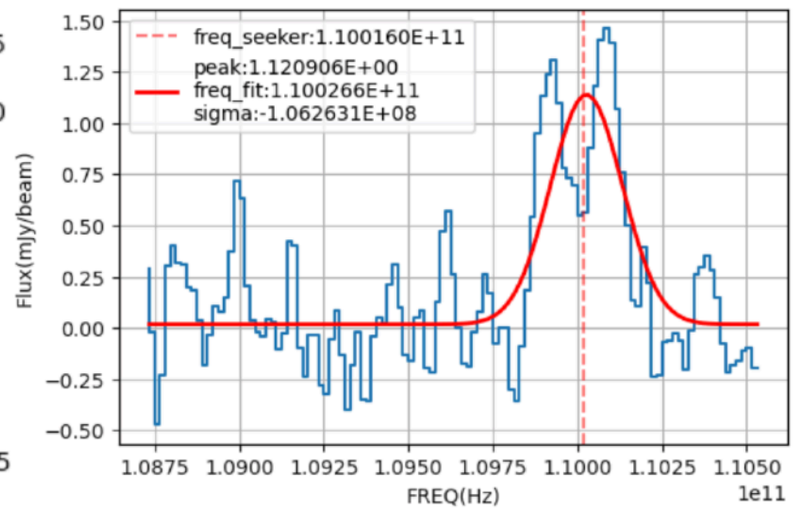
Wang, CCC, FAB in prep.

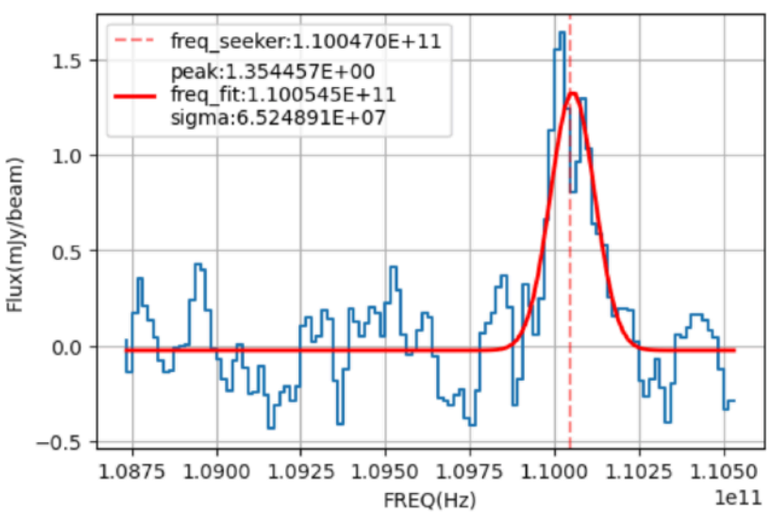
Preliminary

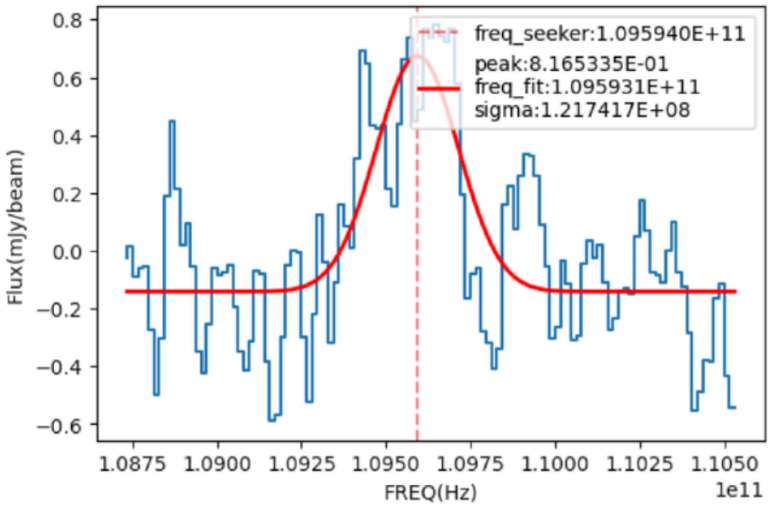
ALMA spectral follow-up

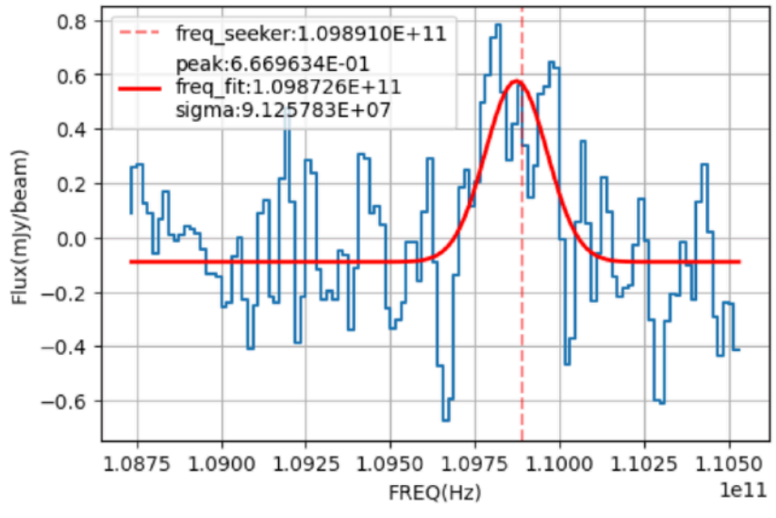
Membership confirmation

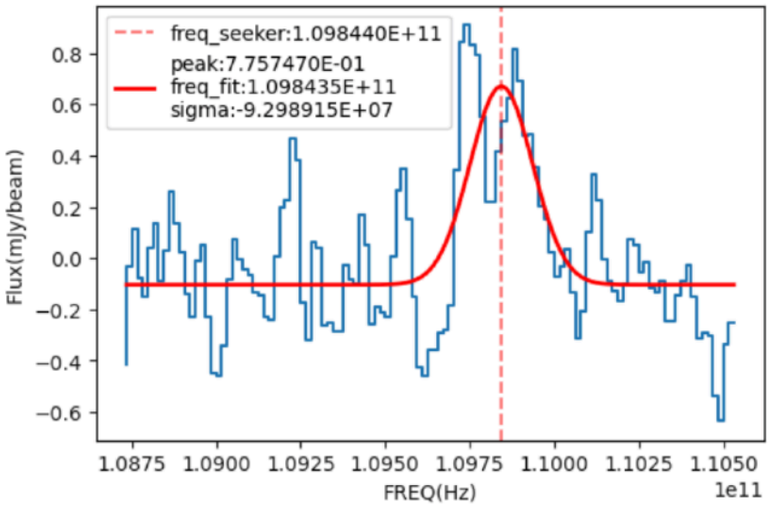










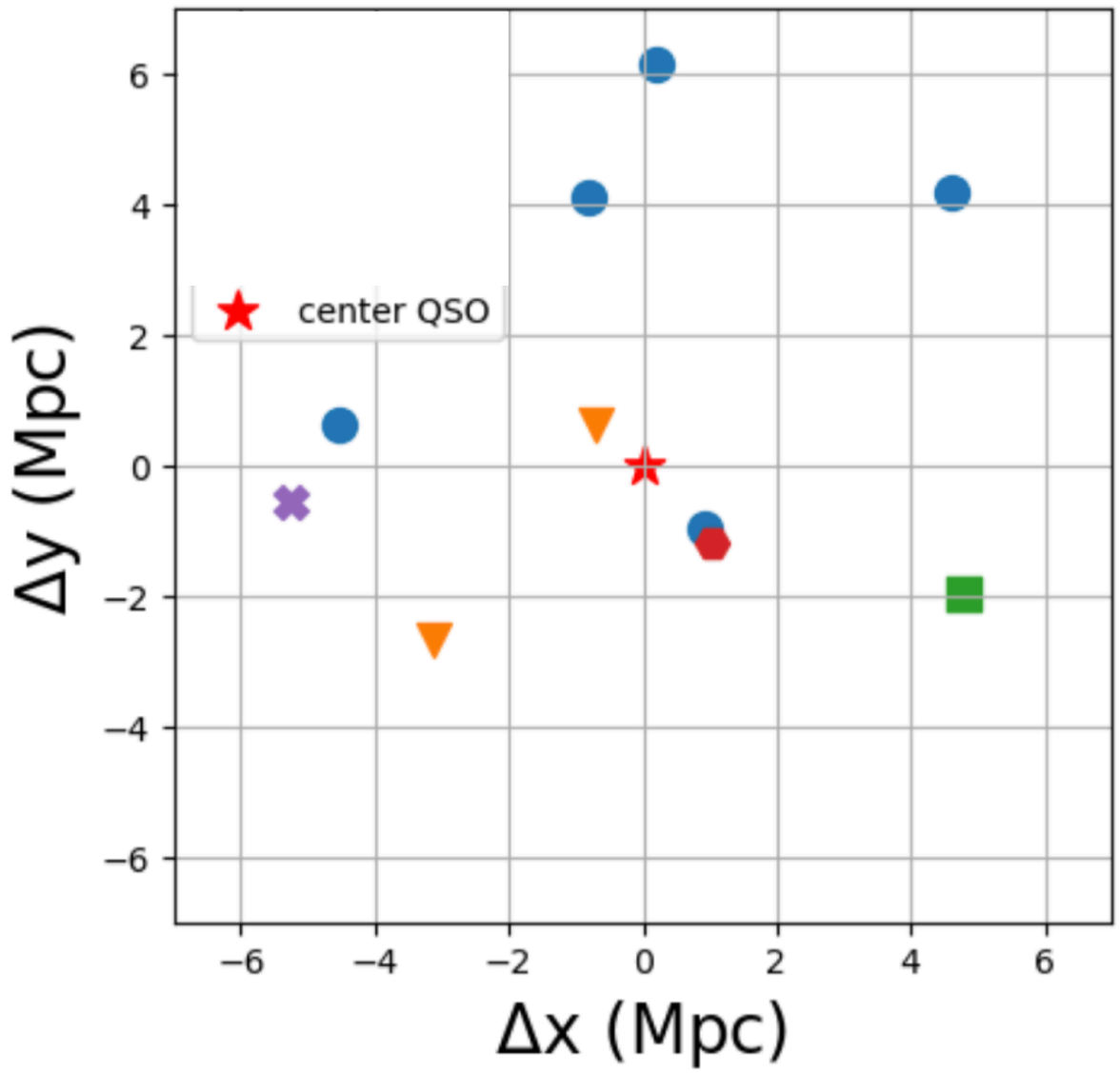


Wang, CCC, FAB in prep.

Preliminary

ALMA spectral follow-up

No coherent structures found

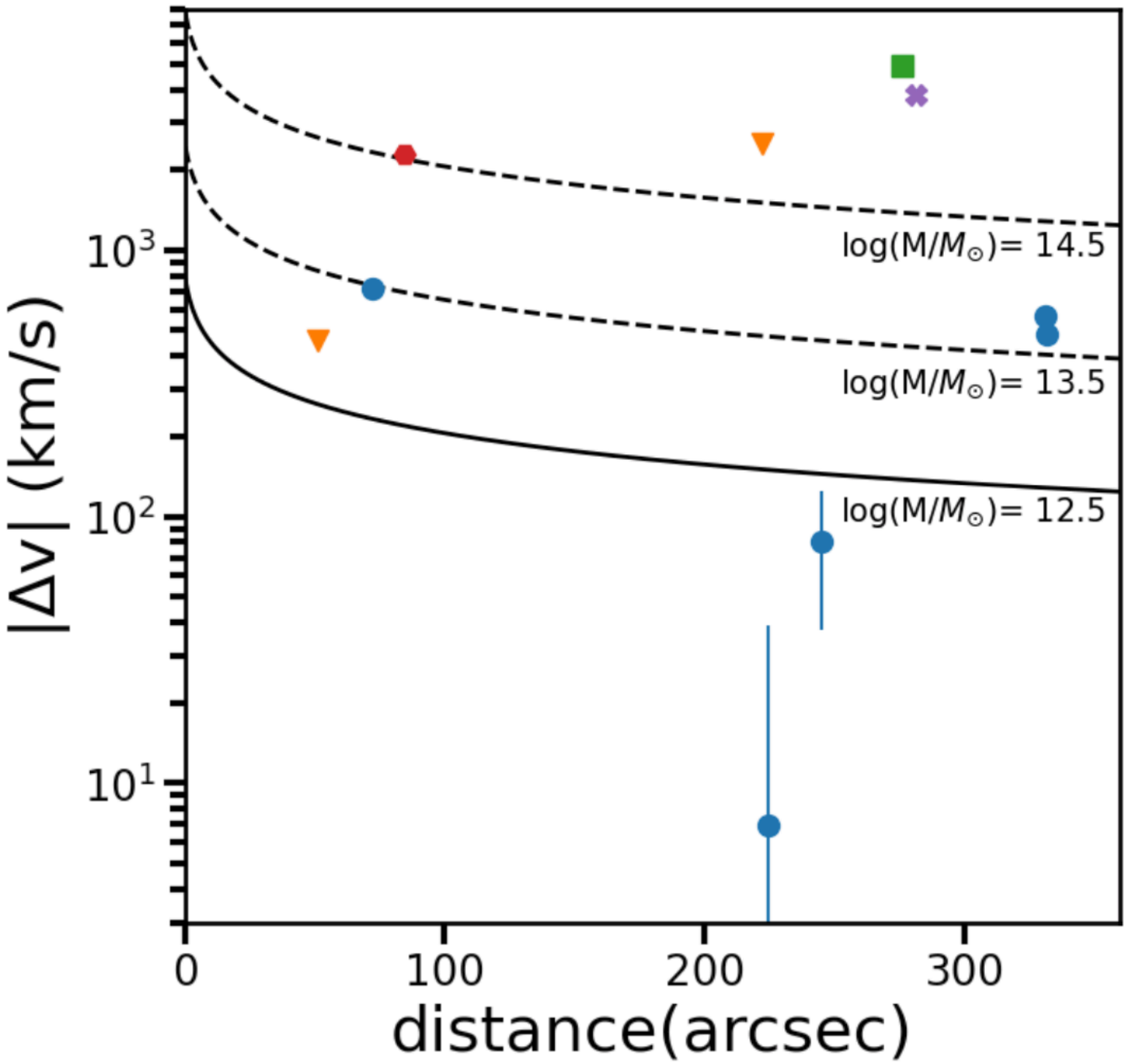


Wang, CCC, FAB in prep.

Preliminary

ALMA spectral follow-up

Some bound and some unbound



Wang, CCC, FAB in prep.

Take away messages

- We have found ubiquitous over-densities of submillimeter sources around a sample of 10 quasars hosting Lyα nebula, confirming intimate co-evolution between dusty star-forming galaxies and quasars.

- Follow-up studies are ongoing in order to confirm membership and understand their physical properties such as phase space distributions and the interstellar medium.

- SCUBA-2 remains a world-leading instrument in mapping the dust-obscured star formation over large scales.