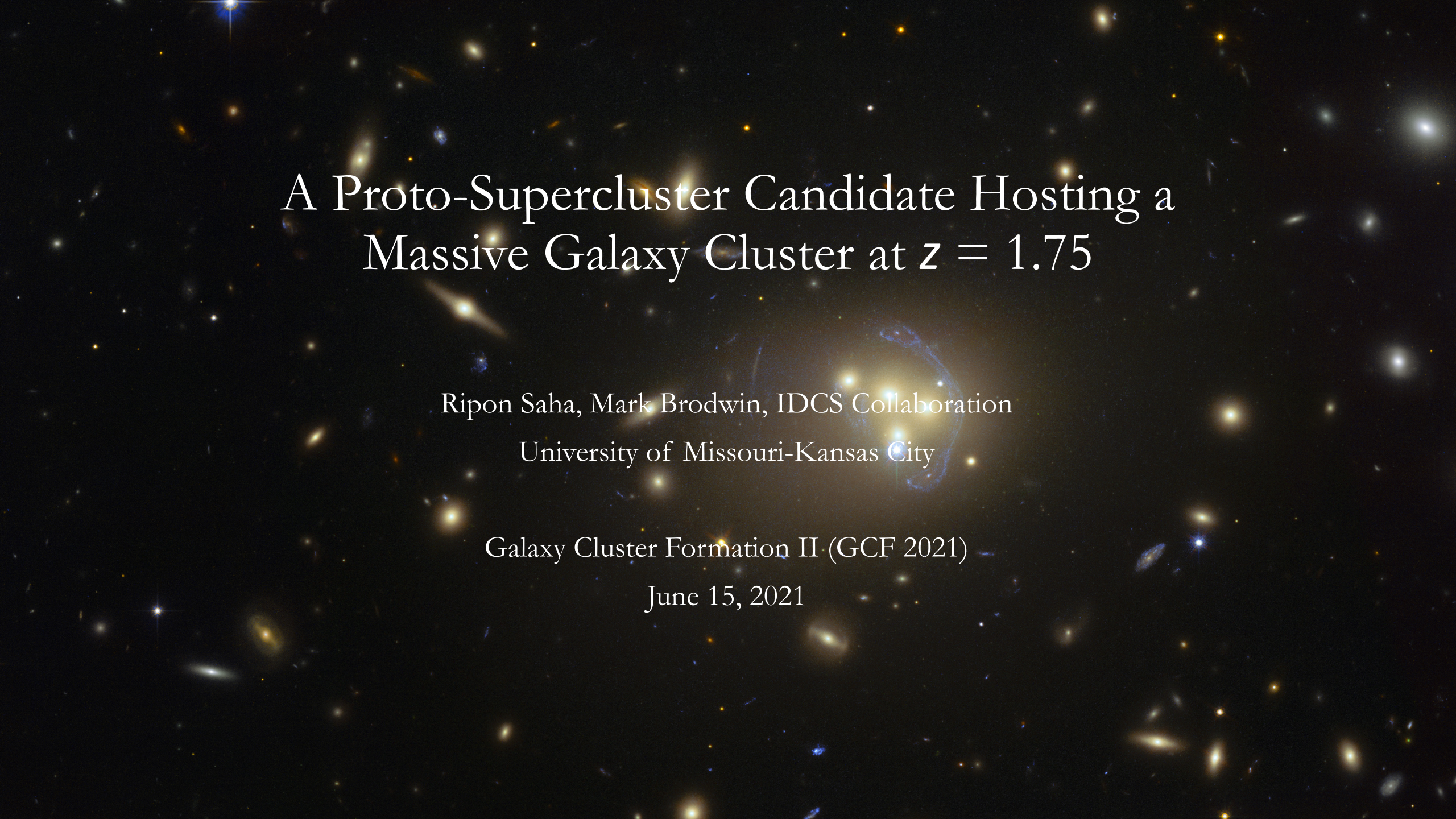


A Proto-Supercluster Candidate Hosting a Massive Galaxy Cluster at $z = 1.75$

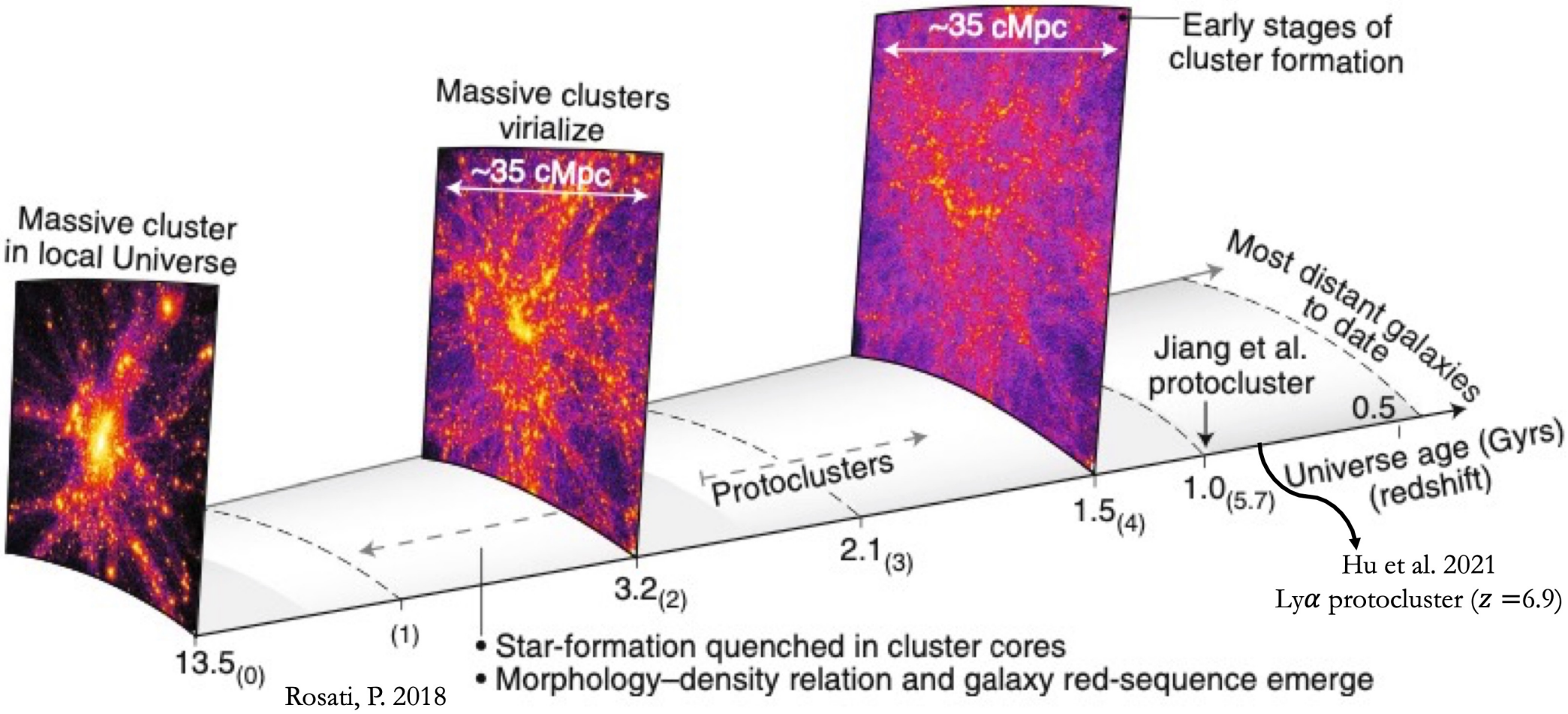
Ripon Saha, Mark Brodwin, IDCS Collaboration

University of Missouri-Kansas City

Galaxy Cluster Formation II (GCF 2021)

June 15, 2021

Evolution of a Galaxy Cluster



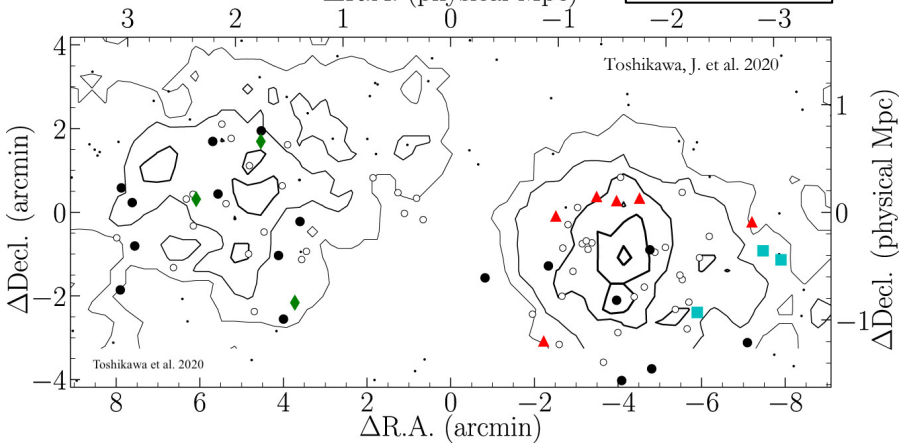
Rosati, P. 2018

Hu et al. 2021
Lyα protocluster (z =6.9)

Primordial Superclusters to Local Superclusters

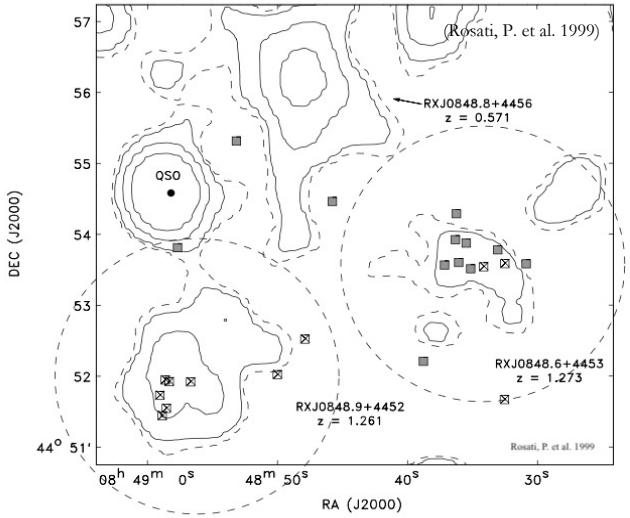
D1RD01

$z = 4.898$

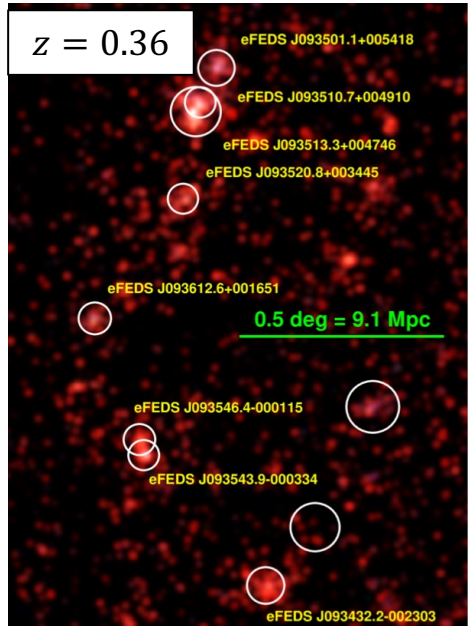


Lynx

$z = 1.3$



$z = 0.36$

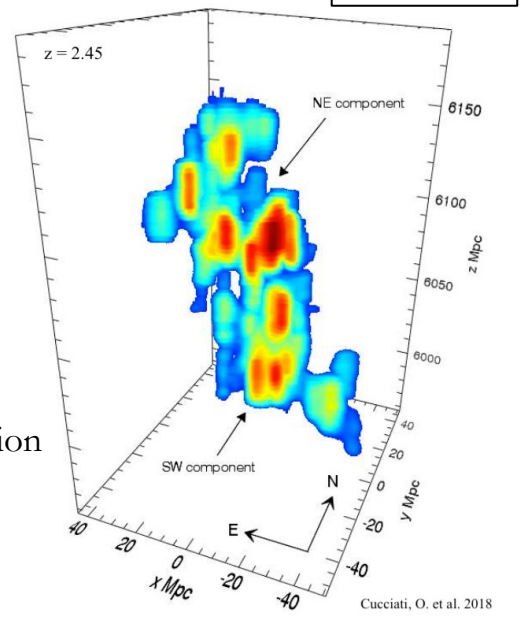


eFEDS

Ghirardini V. et al. 2021

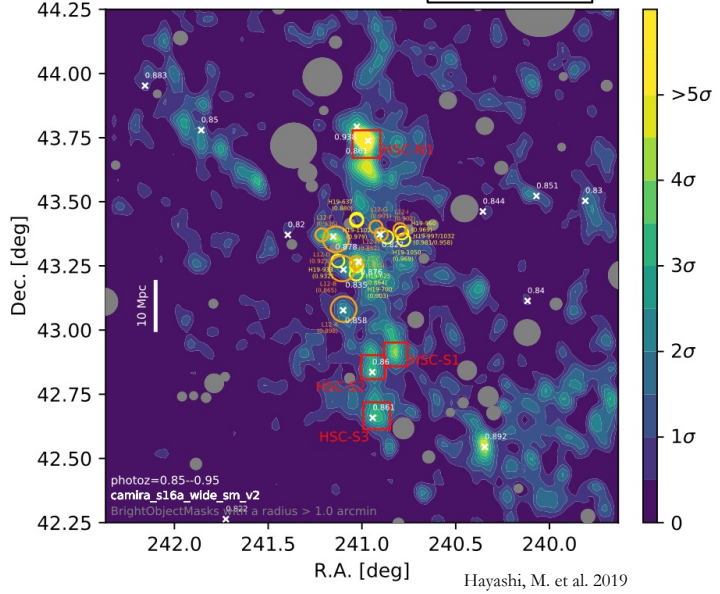
$z = 2.45$

Hyperion

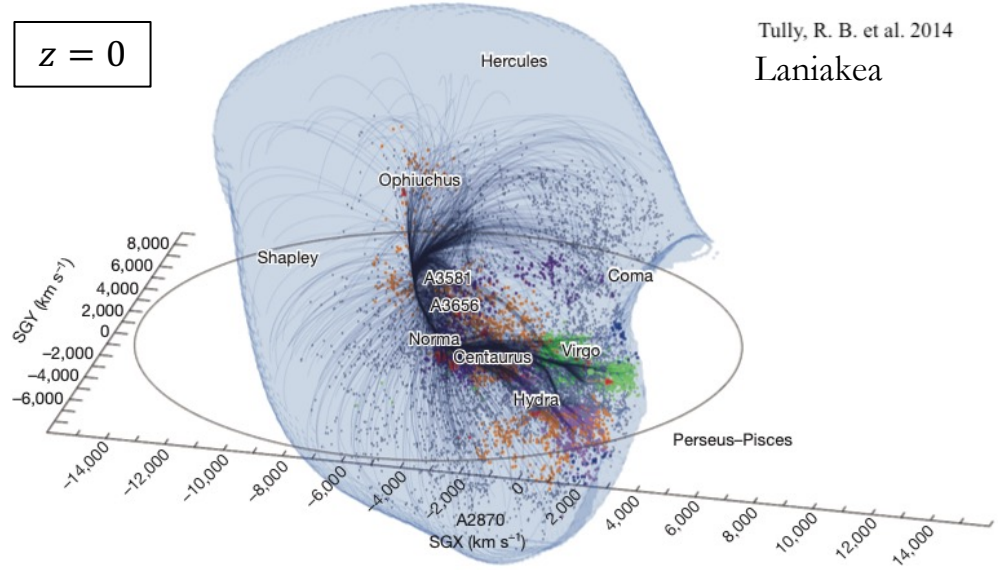


CL-1604

$z = 0.9$



$z = 0$

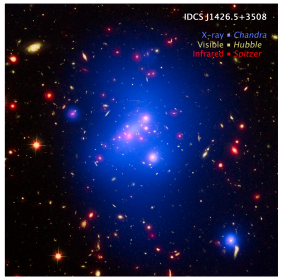


Tully, R. B. et al. 2014

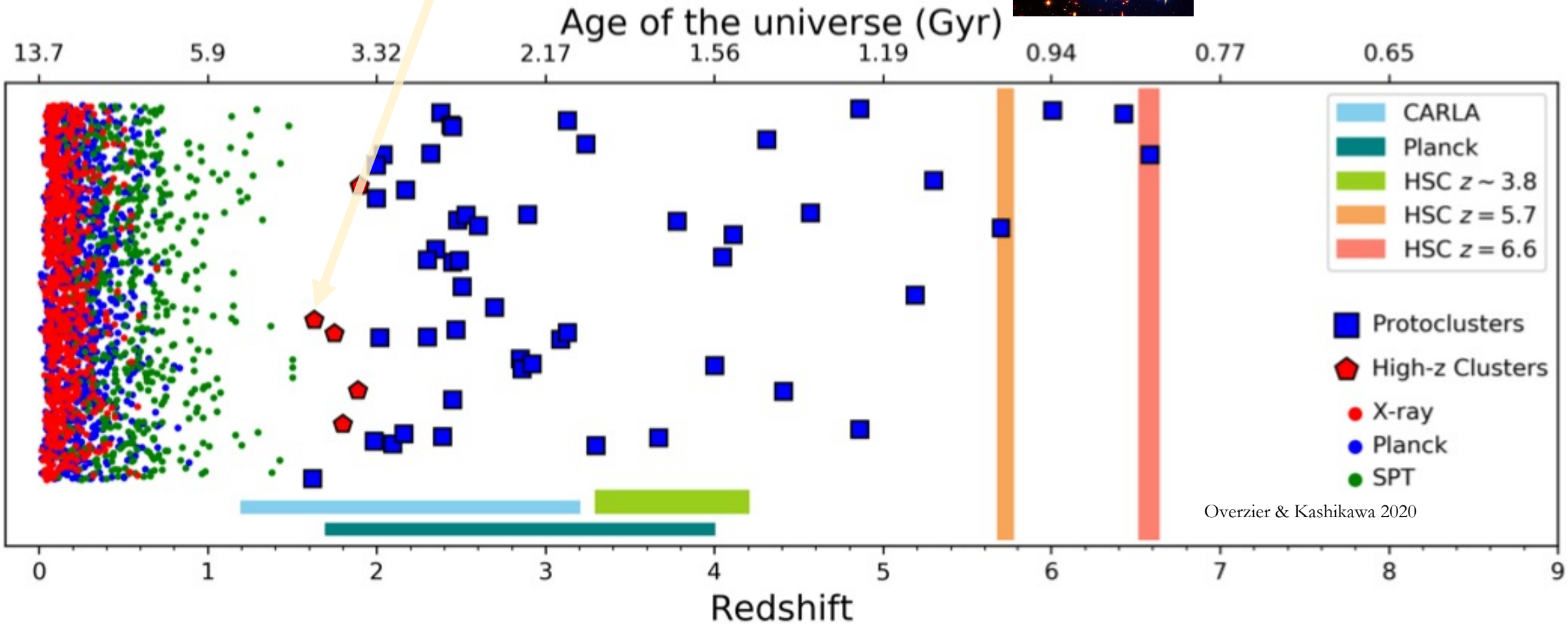
Laniakea

Clusters & Protoclusters

IDCS 1426.5+3508, a very massive cluster at $z = 1.75$ in Boötes

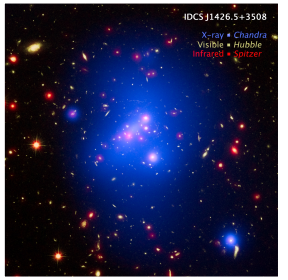


(Stanford. et al. 2012 , Brodwin et al. 2016)

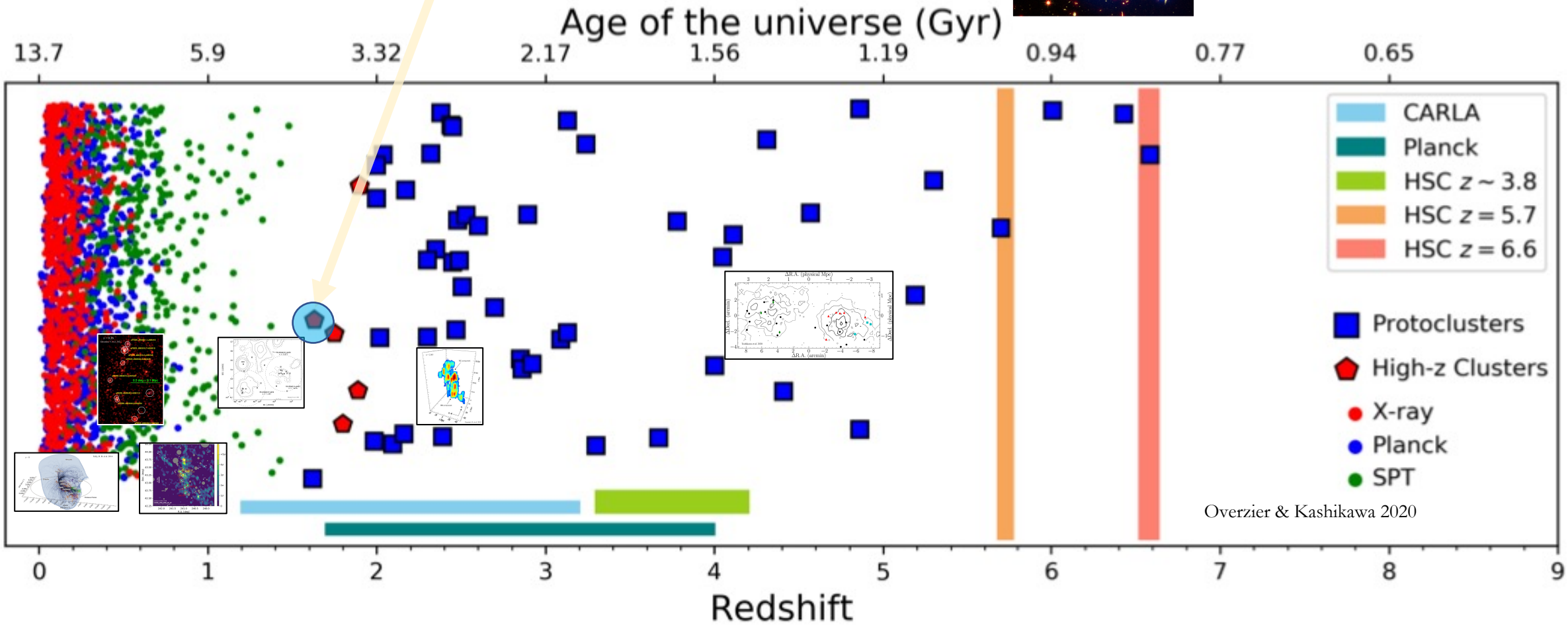


A Proto-supercluster at z =1.75 in Boötes

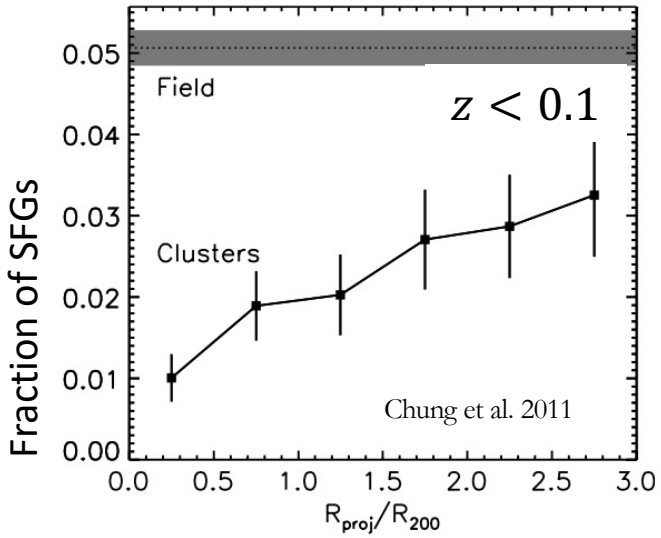
IDCS 1426.5+3508, a very massive cluster at z = 1.75 in Boötes
Embedded in a proto-supercluster

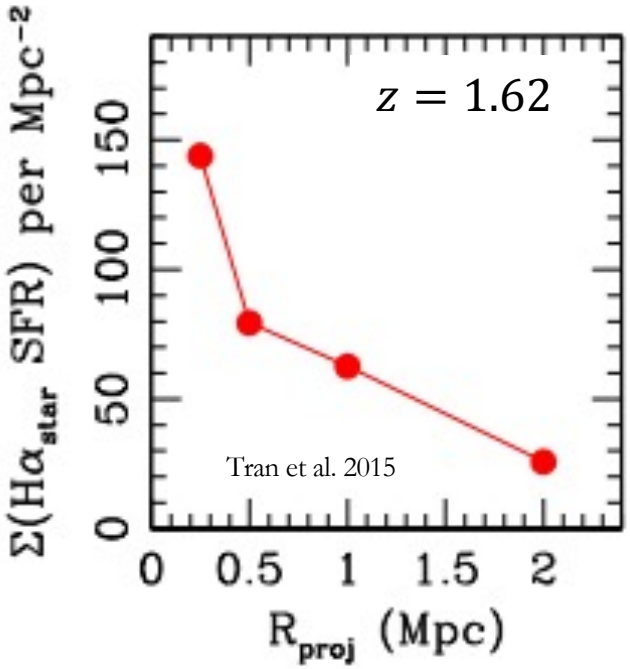


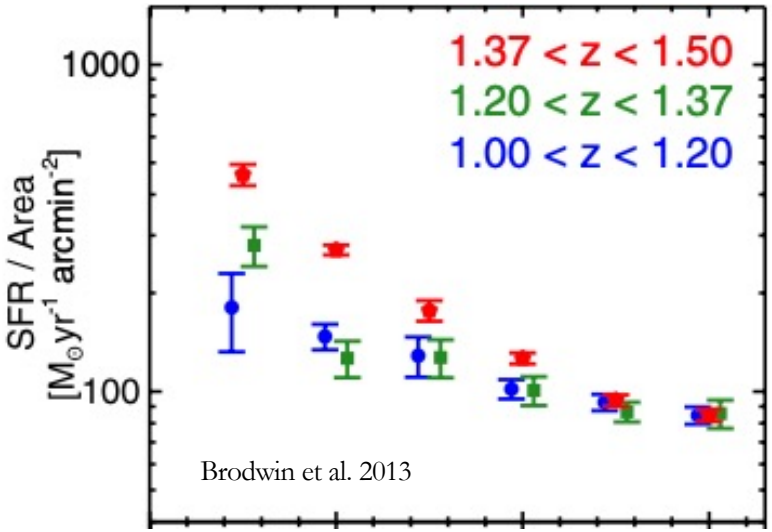
(Stanford. et al. 2012 ,
Brodwin et al. 2016)



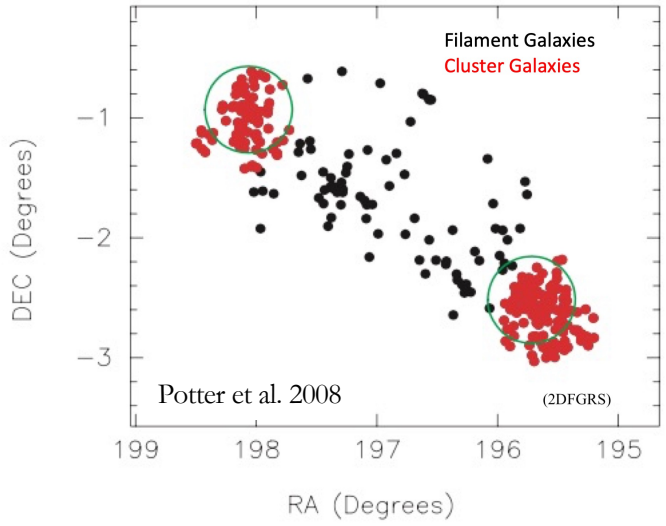
Motivation: Star-formation & AGN activity in High-*z* Clusters

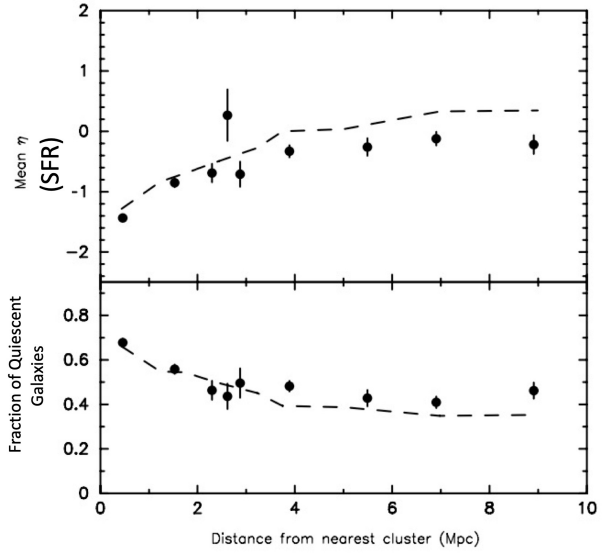


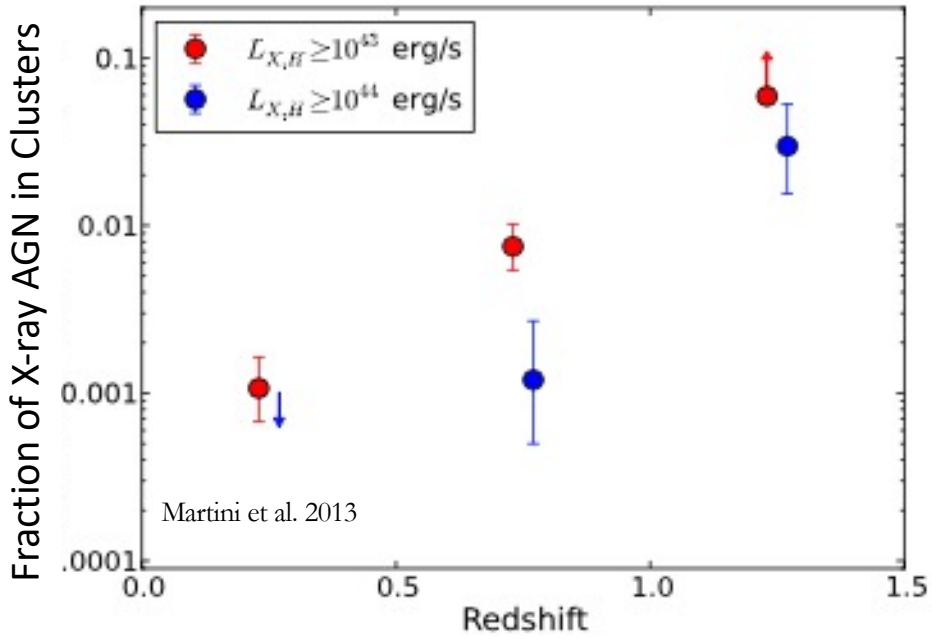




$z \approx 0$

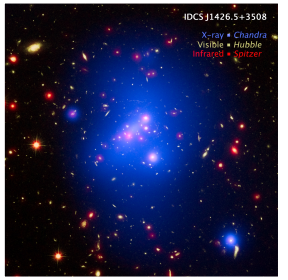






Dust-Obscured Galaxies (DOGs) as Tracers of High-z Structures

IDCS 1426.5+3508, a very massive cluster at $z = 1.75$ in Boötes



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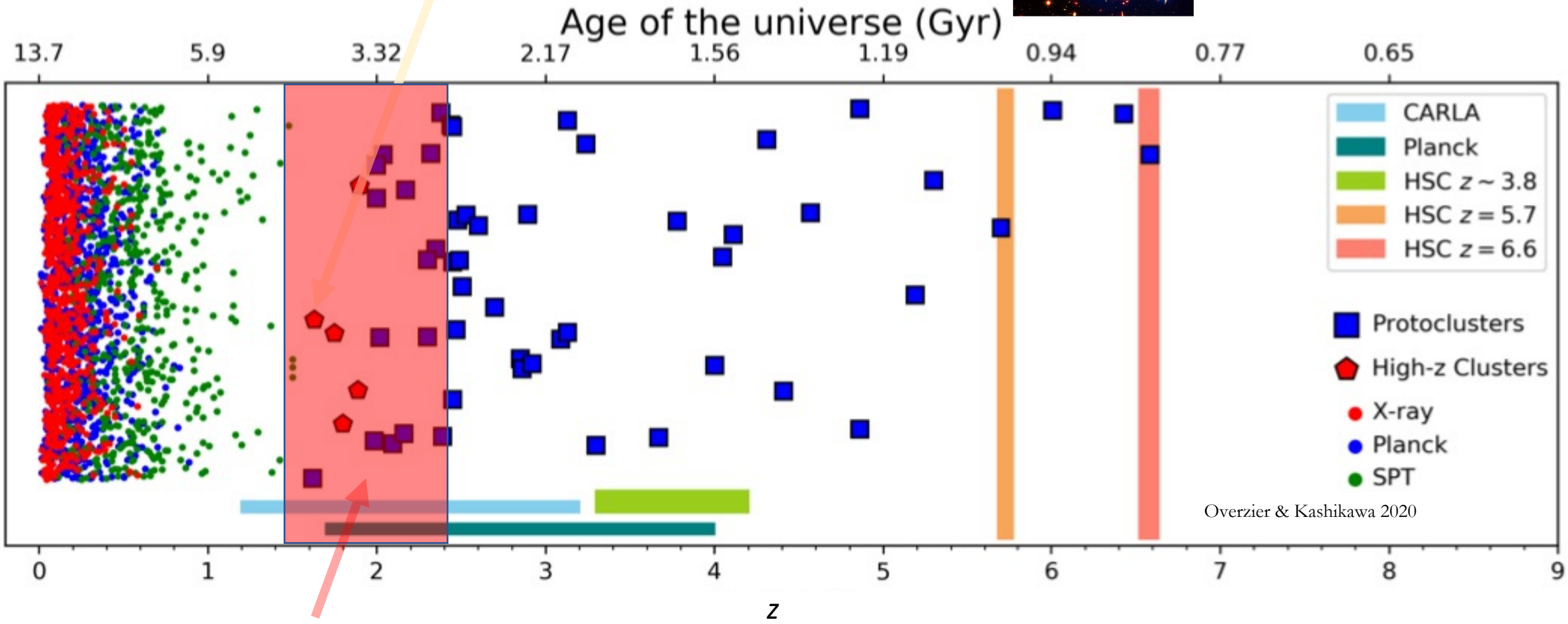
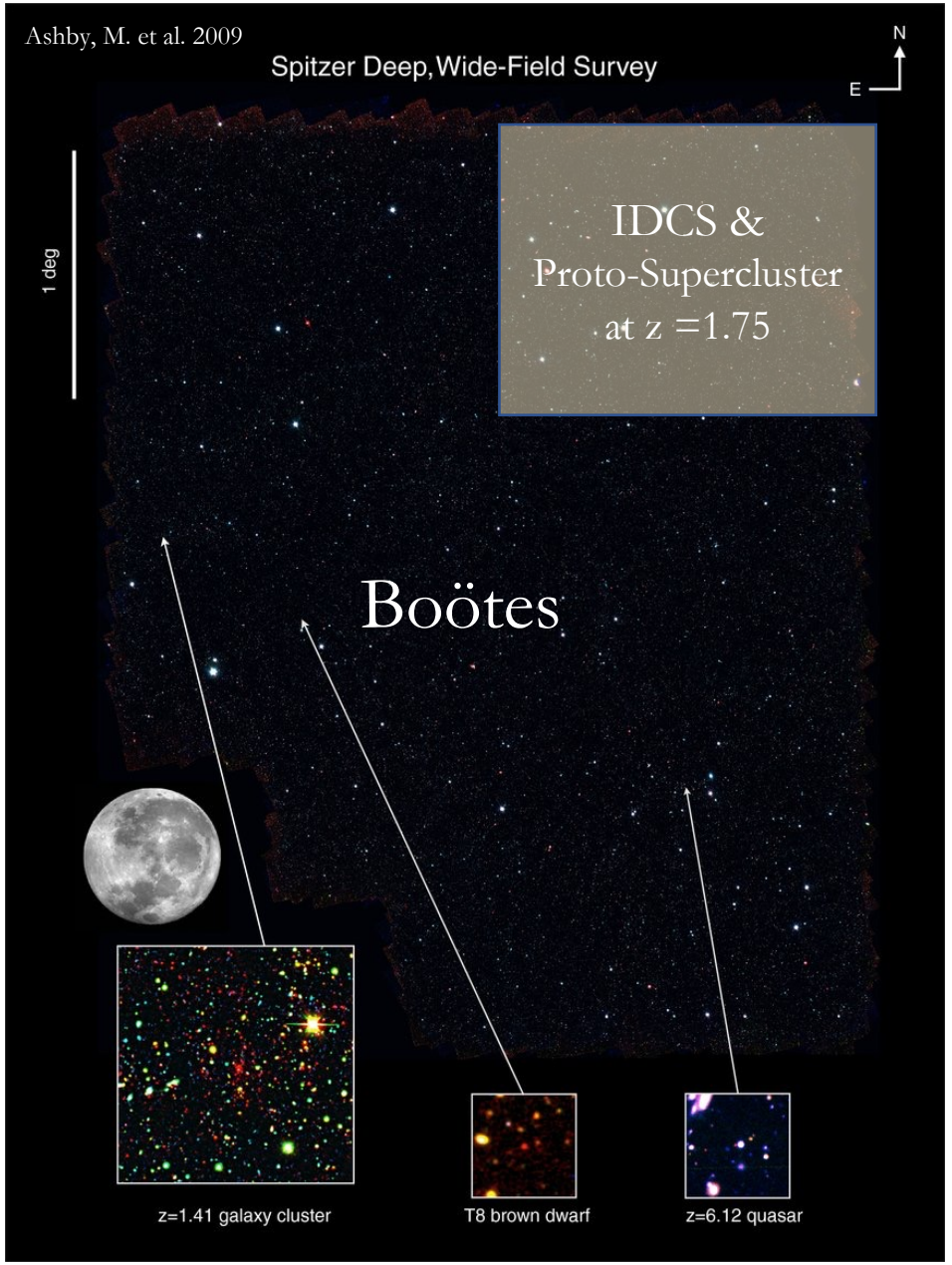


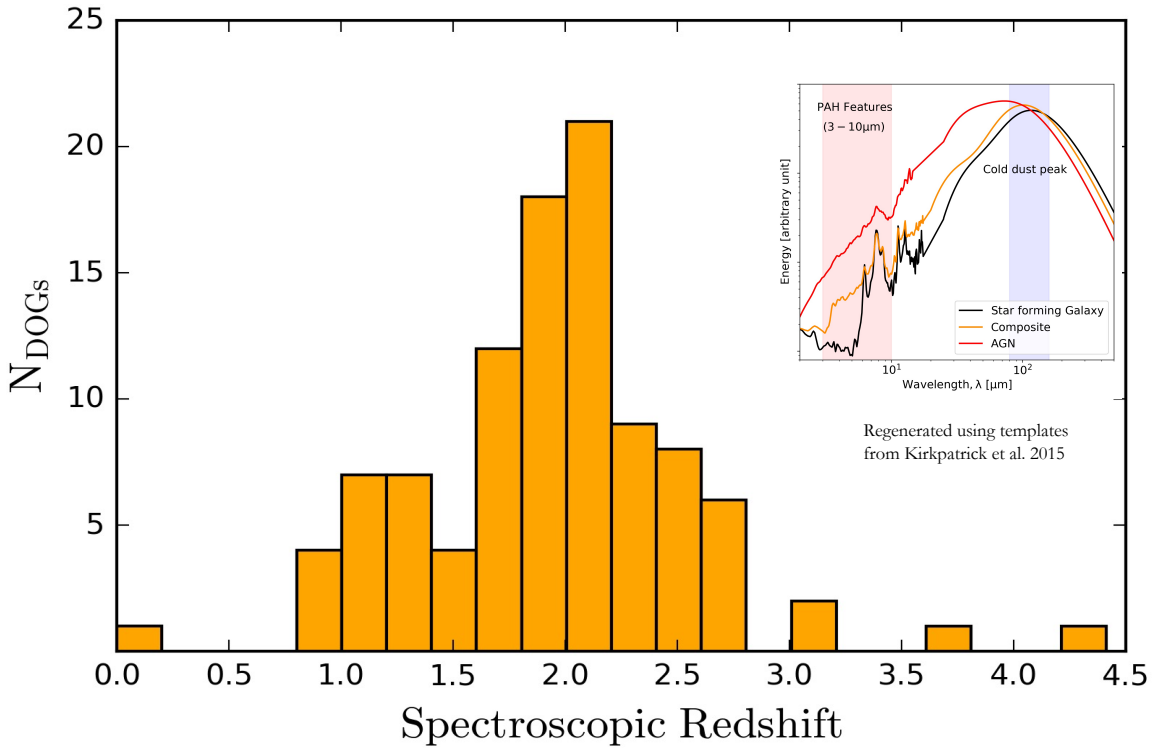
~2600 DOGs : An extremely Star forming and/or AGN population in Boötes

Dust-Obscured Galaxies (DOGs) as Tracers of High-z Structures

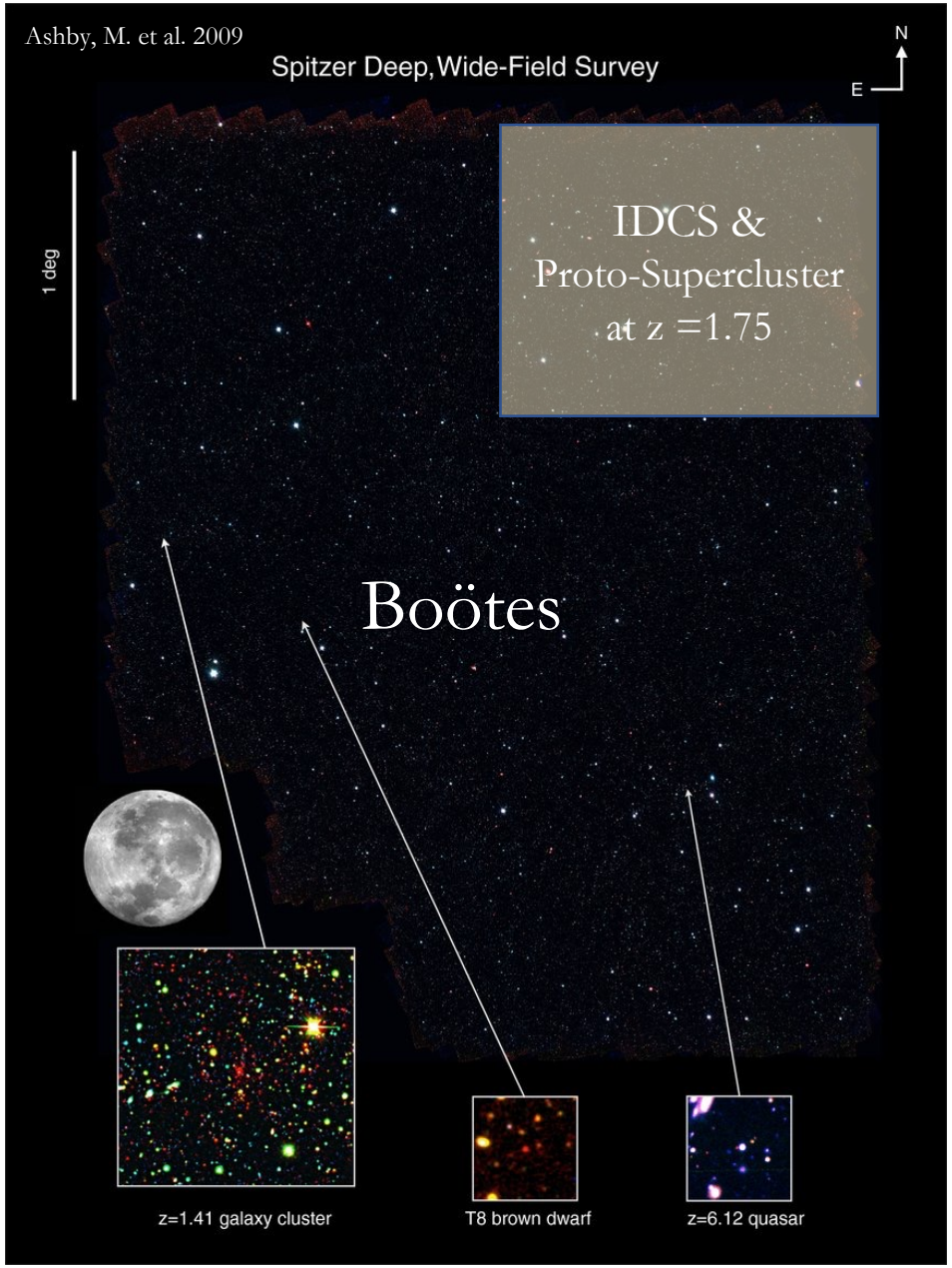


Signposts: Dust-Obscured Galaxies (DOGs)

- MIPS detector on *Spitzer,* Boötes *field*
- **24 μm – selected ULIRGs (SFGs/AGNs) (~ 2600)**
- $F_\nu(24\mu m)/F_\nu(R) \gtrsim 1000$
- $z \sim 2$ *with* $\sigma \sim 0.45$ (Dey, A. et al. 2008)



Dust-Obscured Galaxies (DOGs) as Tracers of High-z Structures



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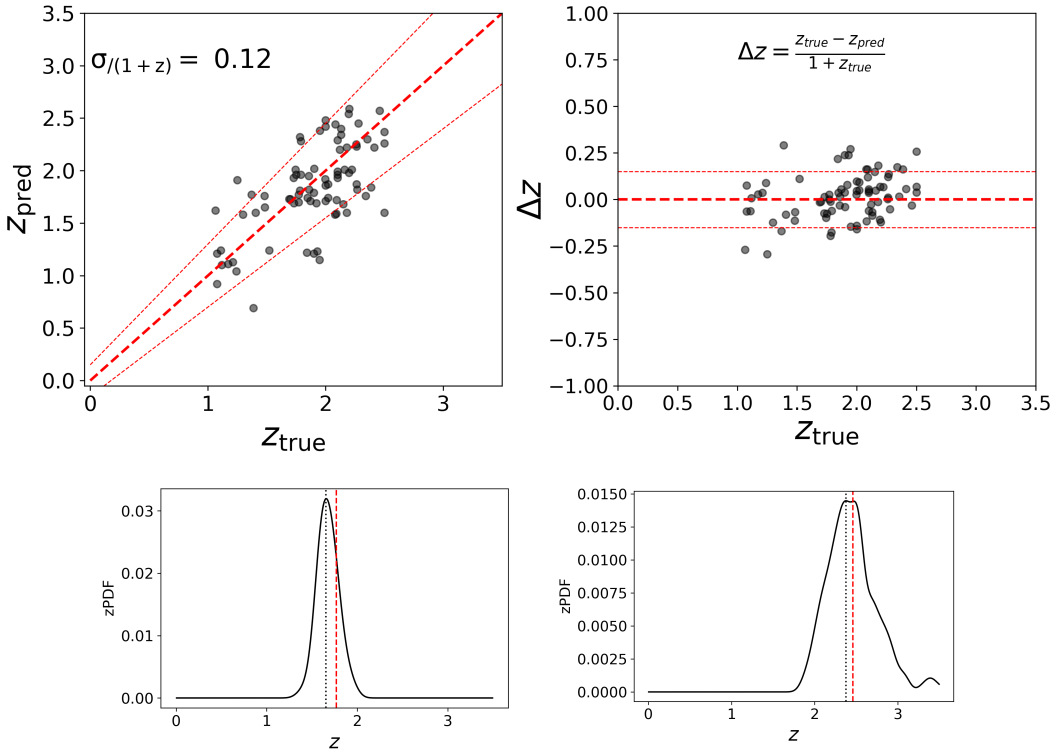
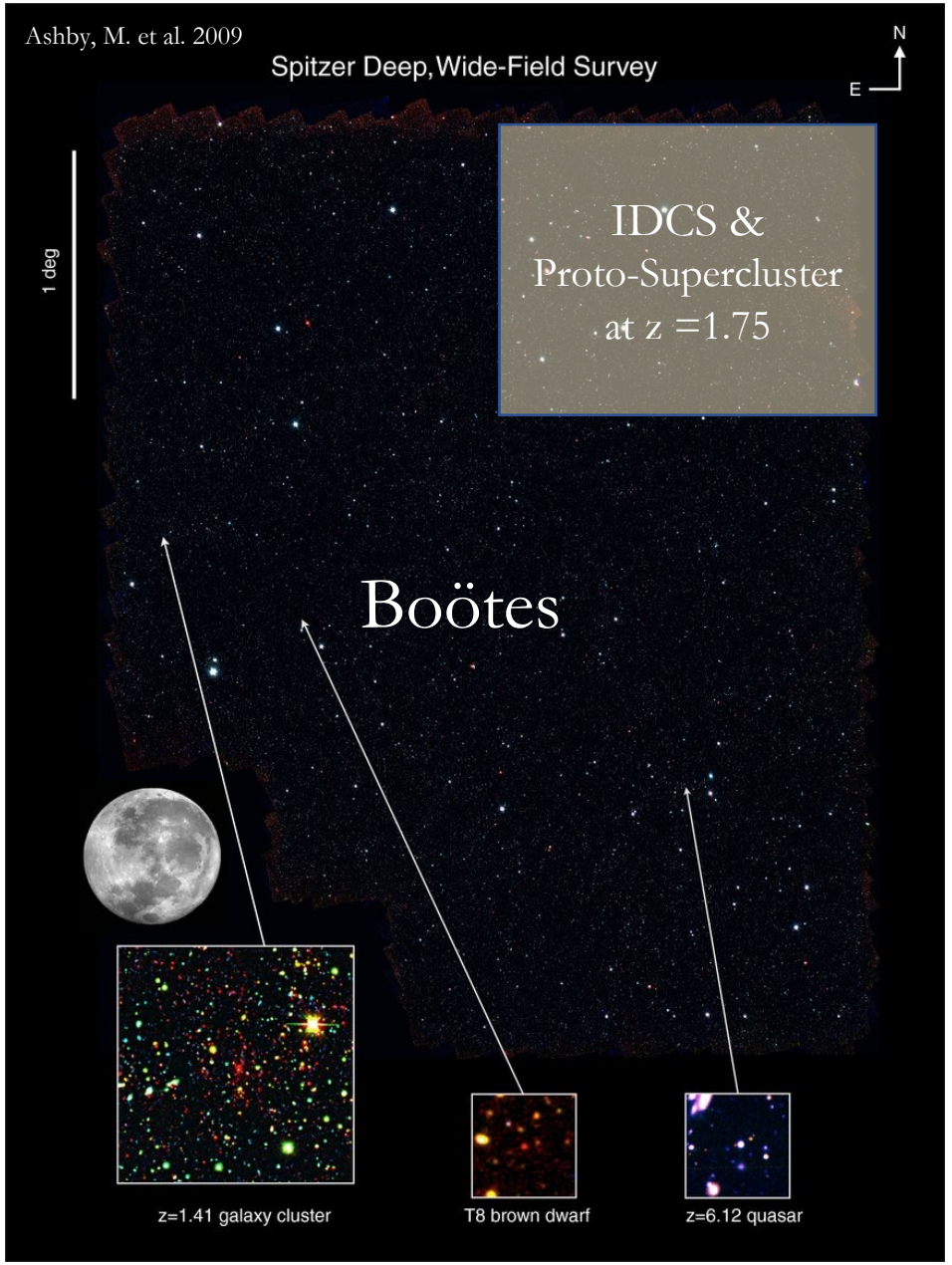
ML redshift using 13 band photometry for the DOGs
Deep learning regression network.

TensorFlow



Dust-Obscured Galaxies (DOGs) as Tracers of High-z Structures



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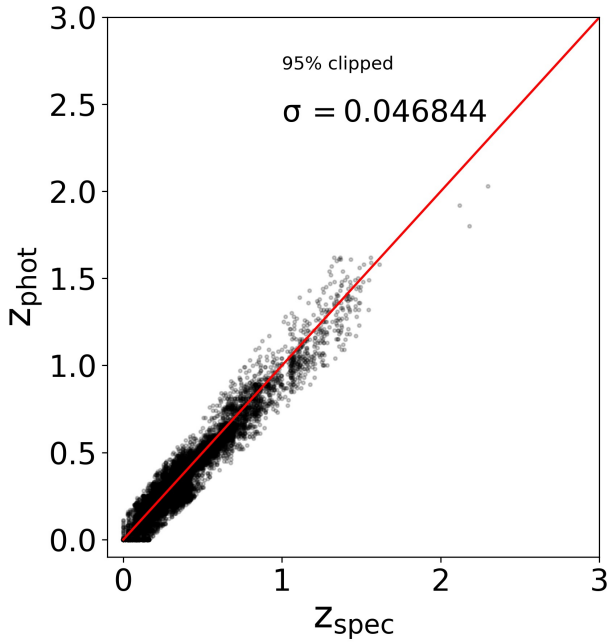
4.5 μm-selected galaxies at z = 1.75 from SDWFS (Spitzer Deep, Wide Field Survey in Boötes) using Template-fitting Redshifts

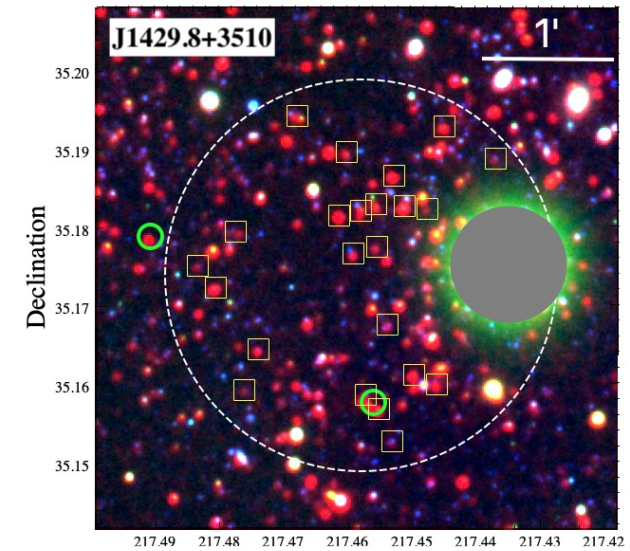


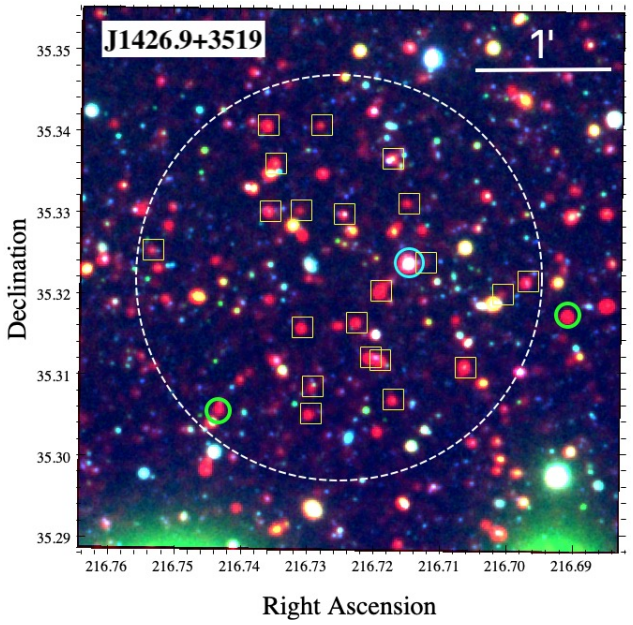
1. Search for overdensities in the photo-z Galaxies at z=1.75 using DOGs as signposts.

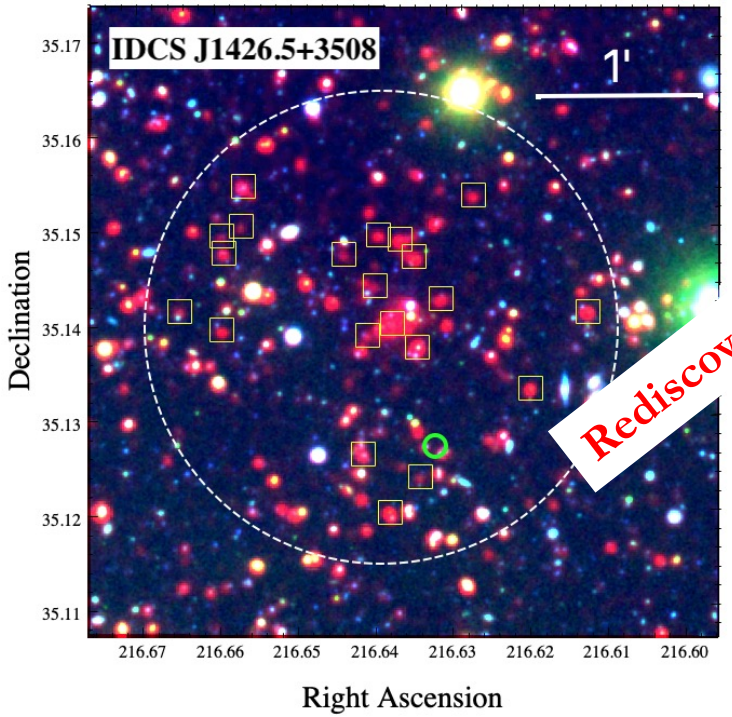
2. We used the full PDF of the photo-z to determine redshift. **~40000 galaxies are found to be consistent with z=1.75 over the entire field of Boötes**

Dust-Obscured Galaxies (DOGs) as Tracers of High-z Structures

Large-Scale Structures at z = 1.75 with > 4σ significance







KPNO B, I + Spitzer 4.5 um

A Proto-supercluster at z =1.75 in Boötes

Green : DOGs (Signposts)
Yellow: > 4σ candidates
White: ~3σ candidates
Red Stars: Speczs

Search Radius ≈ 2 cMpc (cluster-scale)

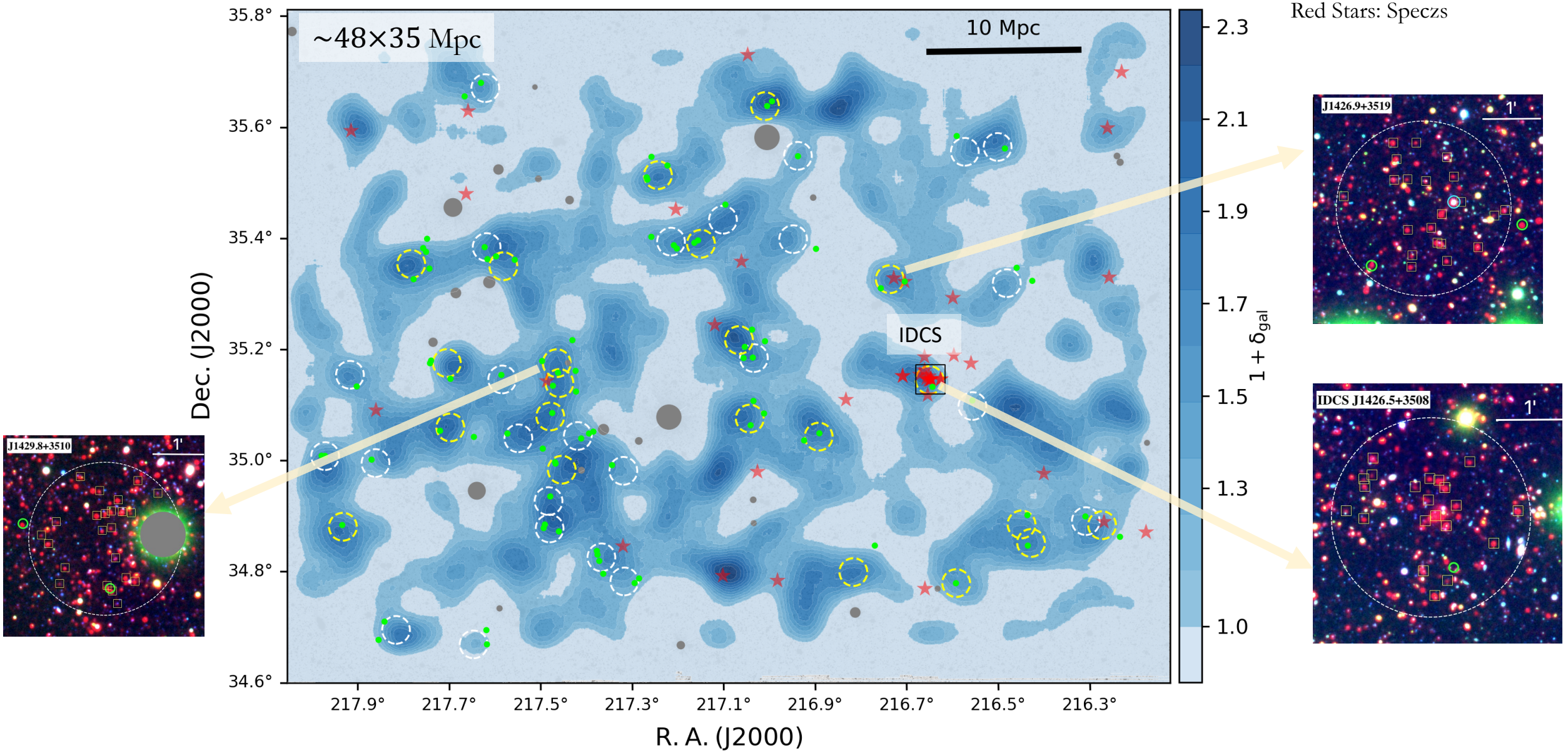


Image Credit: NASA, ESA, and the Hubble Heritage Team (STScI/AURA)

A Proto-supercluster at z =1.75 in Boötes

Search Radius ≈ 2 cMpc (cluster-scale)

Green : DOGs (Signposts)
Yellow: $> 4\sigma$ candidates
White: $\sim 3\sigma$ candidates
Red Stars: Speczs
Black Circle: DOGs | $z = 1.75$

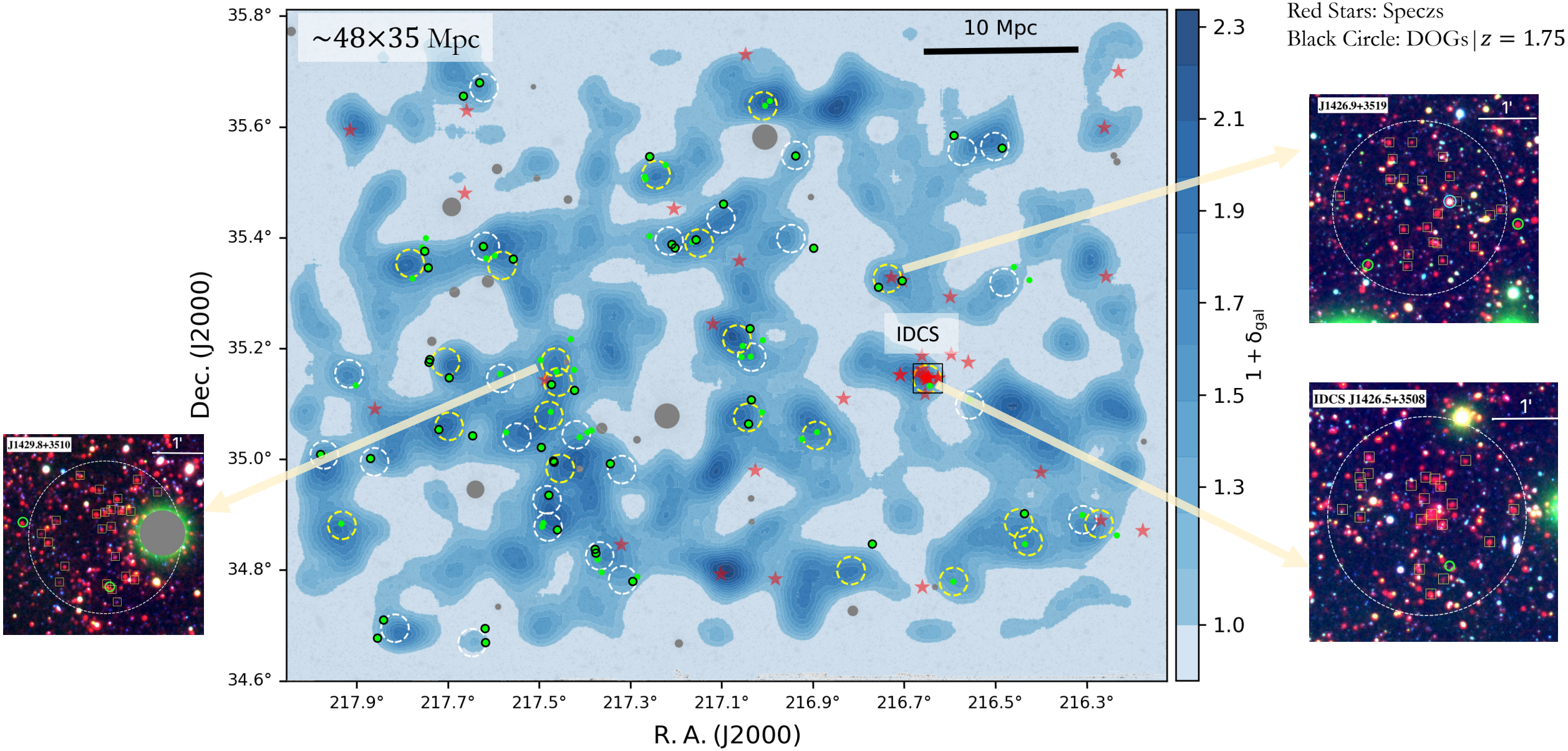
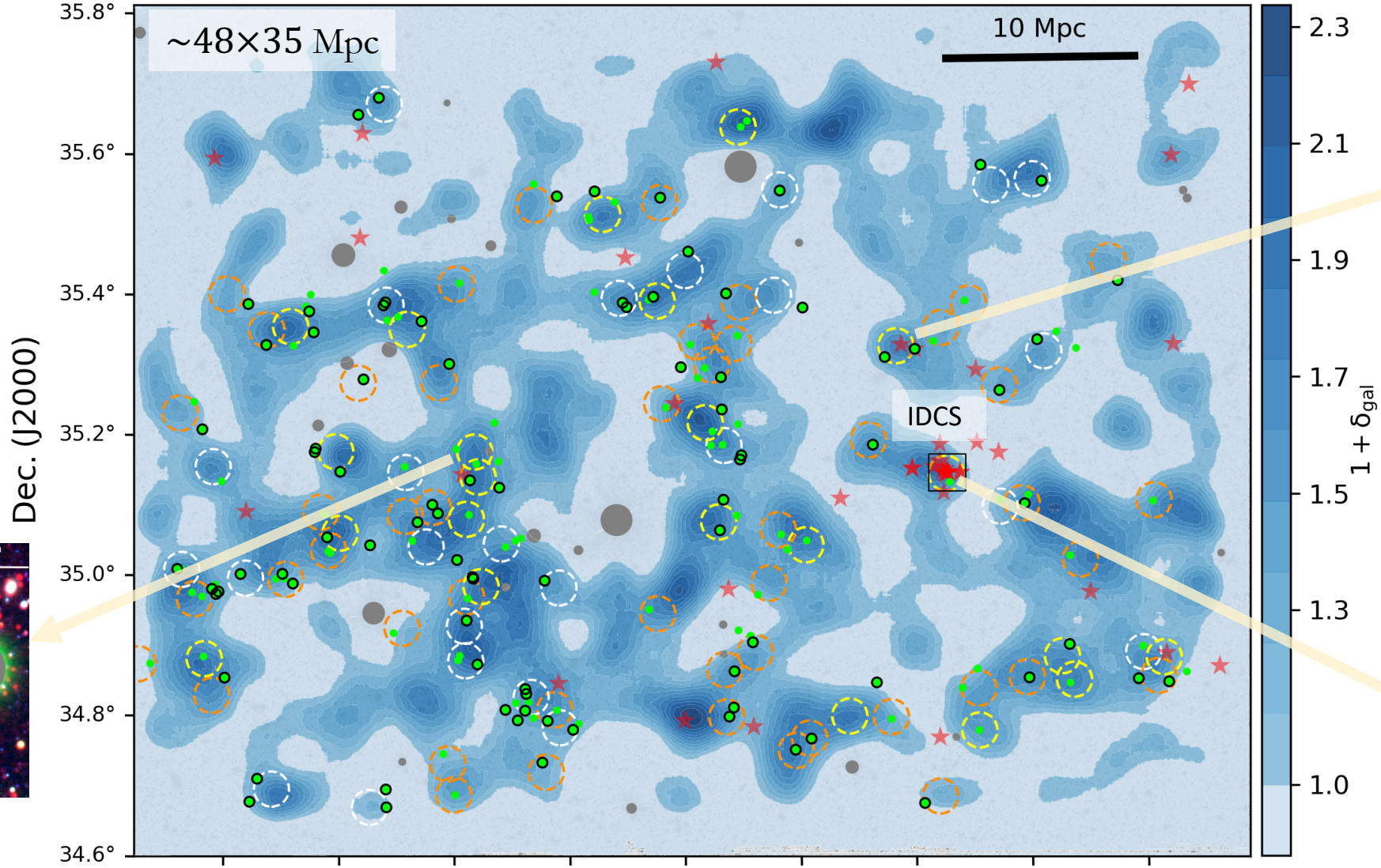


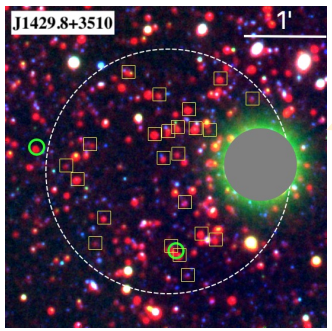
Image Credit: NASA, ESA, and the Hubble Heritage Team (STScI/AURA)

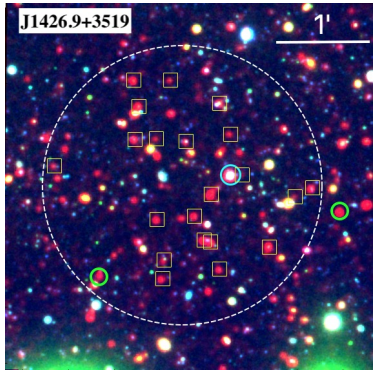
A Proto-supercluster at z =1.75 in Boötes

Search Radius ≈ 2 cMpc (cluster-scale)

Green : DOGs (Signposts)
Yellow: $> 4\sigma$ candidates
White: $\sim 3\sigma$ candidates
Red Stars: Speczs
Black Circle: DOGs | $z = 1.75$
Orange: $\sim 2\sigma$ candidates







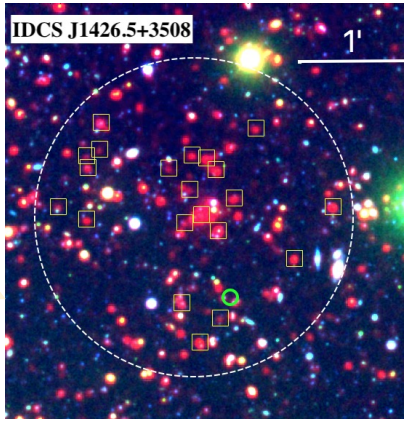


Image Credit: NASA, ESA, and the Hubble Heritage Team (STScI/AURA)

A Proto-supercluster at z =1.75 in Boötes

Search Radius ≈ 4.5 cMpc (protocluster-scale)

Green : DOGs (Signposts)
Yellow: $> 4\sigma$ candidates
White: $\sim 3\sigma$ candidates
Red Stars: Speczs
Black Circle: DOGs | $z = 1.75$
Orange: $\sim 2\sigma$ candidates

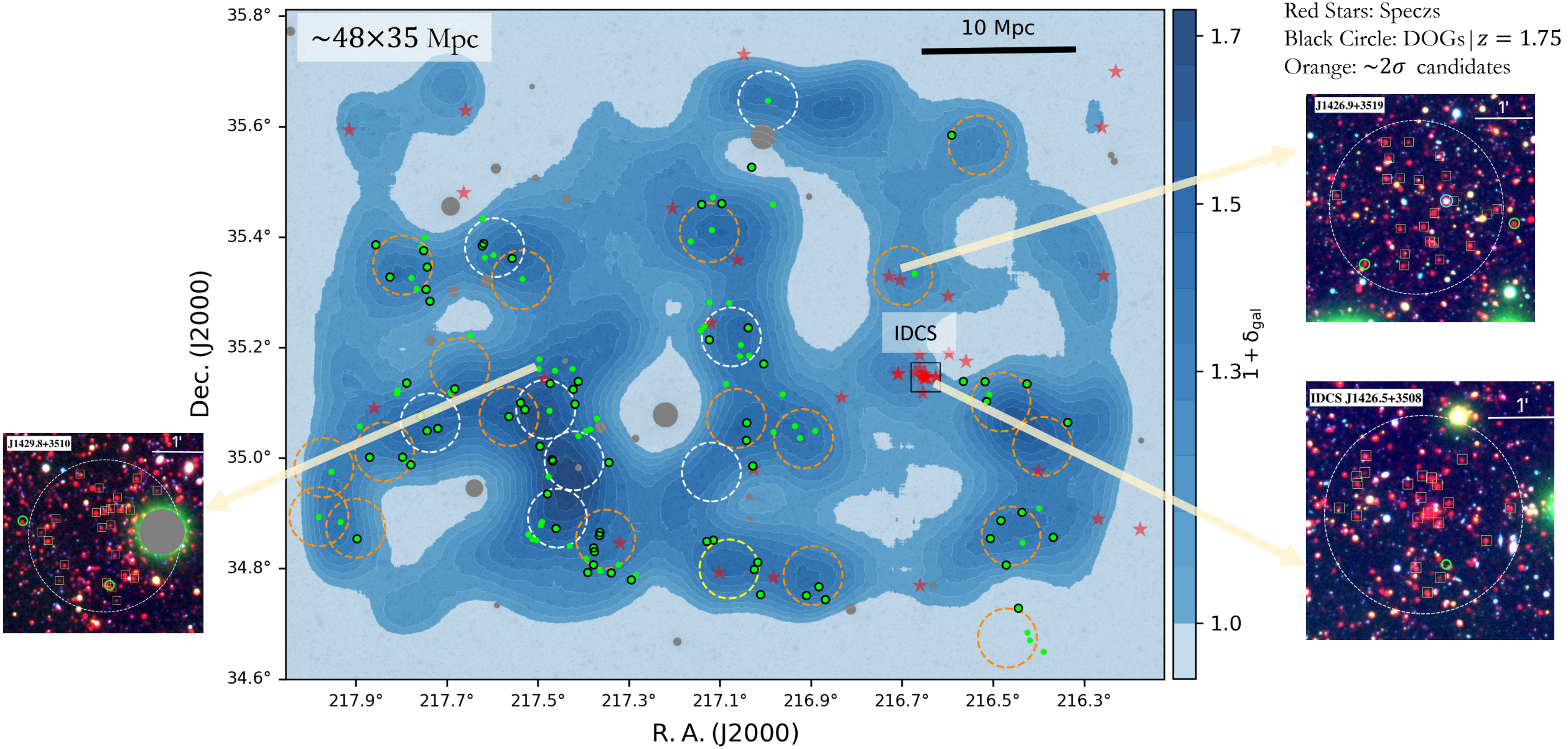
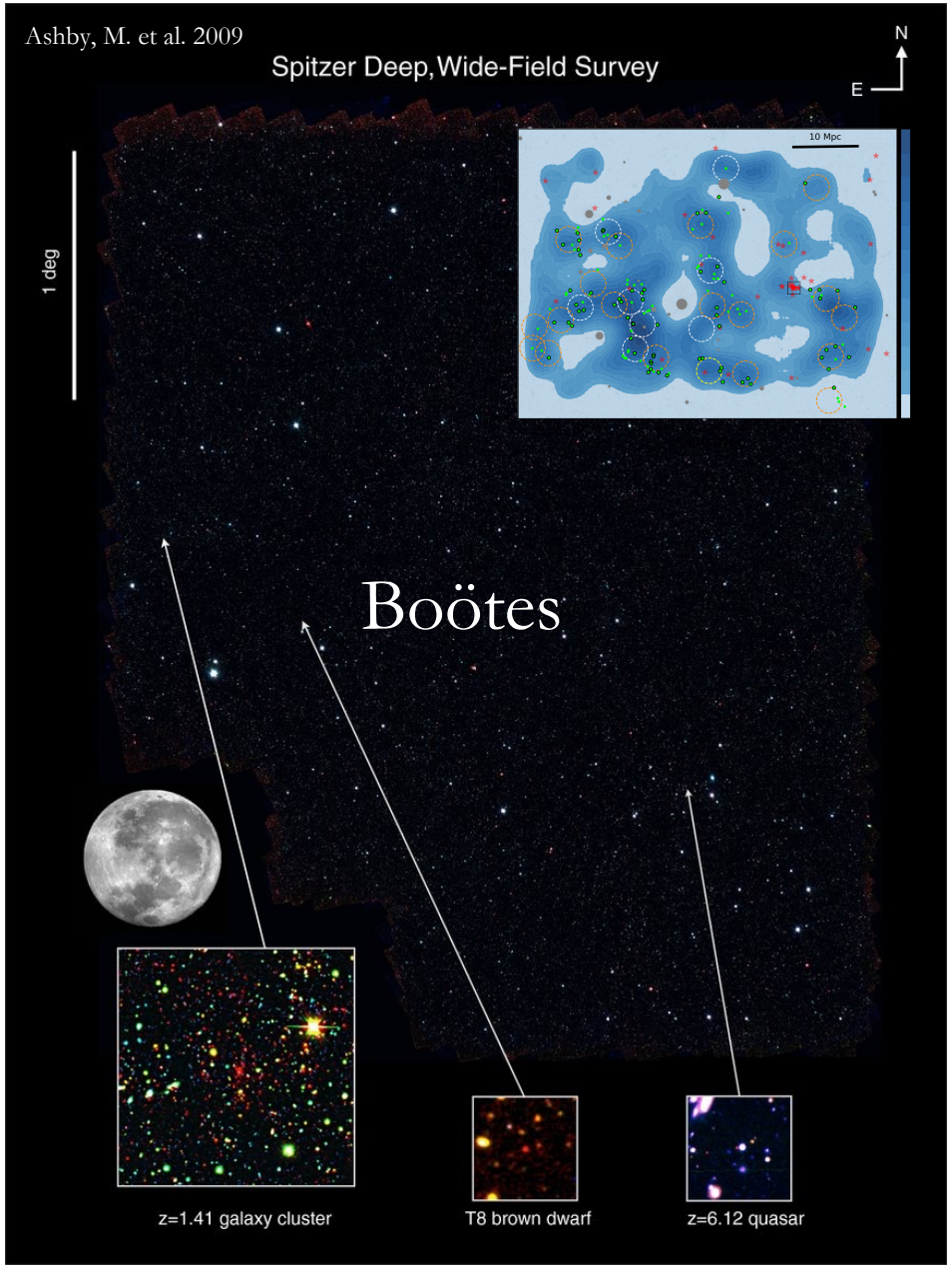


Image Credit: NASA, ESA, and the Hubble Heritage Team (STScI/AURA)

A Proto-supercluster at z =1.75 in Boötes



Auto-correlation function of the DOG sample

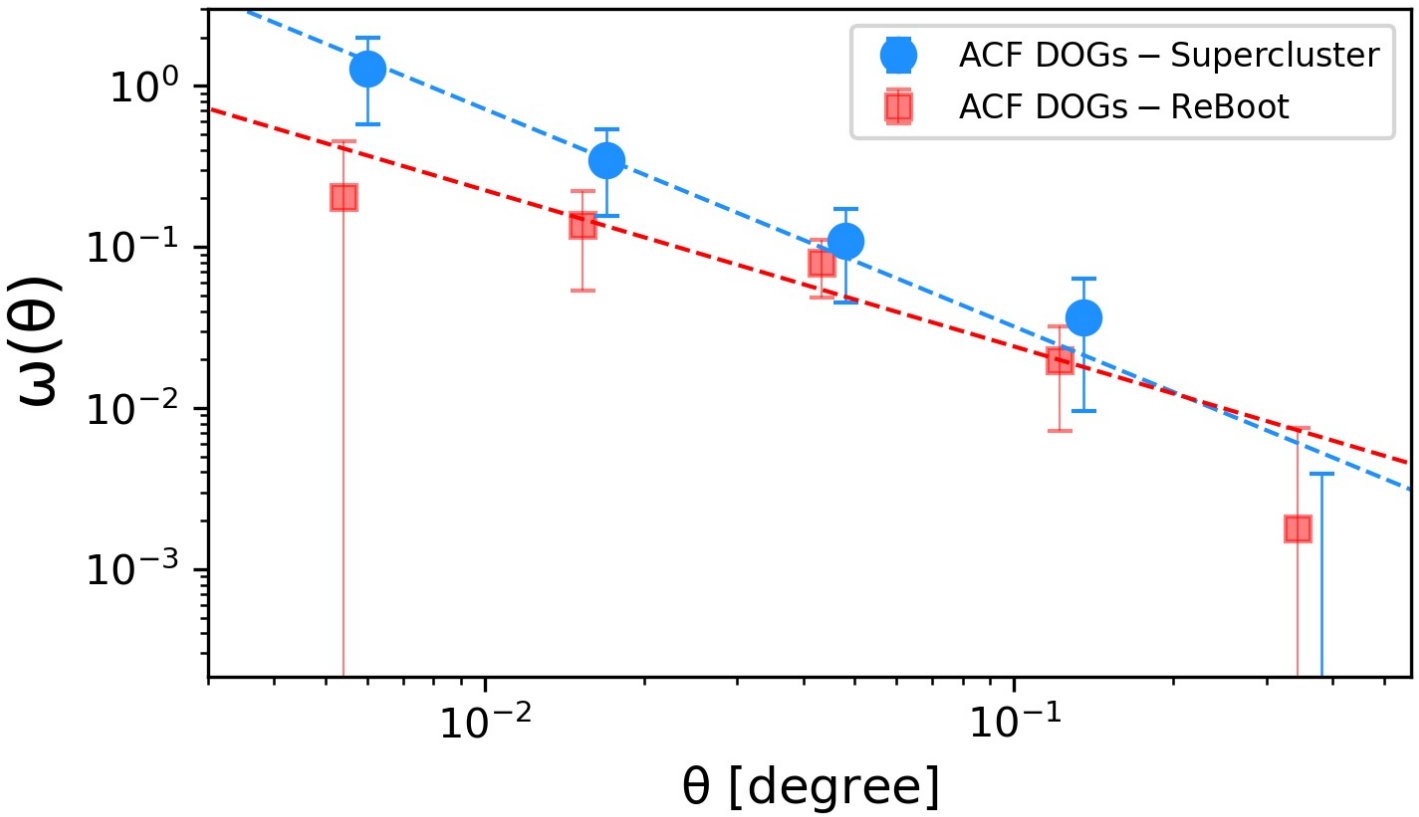
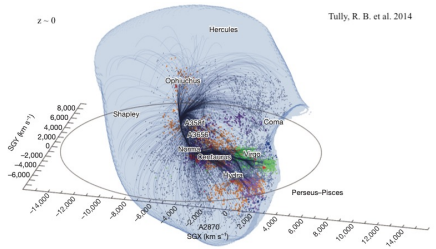


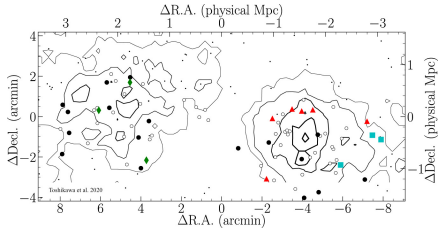
Image Credit: NASA, ESA, and the Hubble Heritage Team (STScI/AURA)

A Proto-supercluster at z =1.75 in Boötes

Future Work



Z=0



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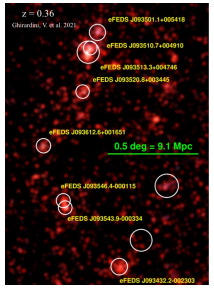
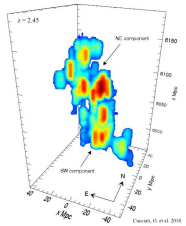
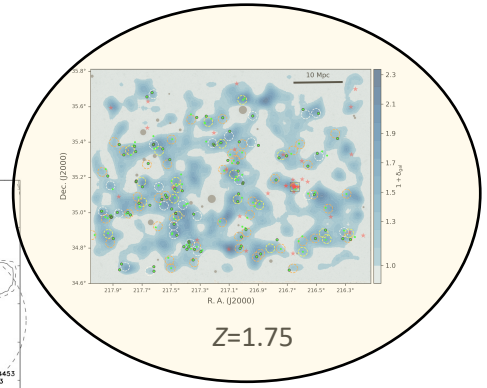


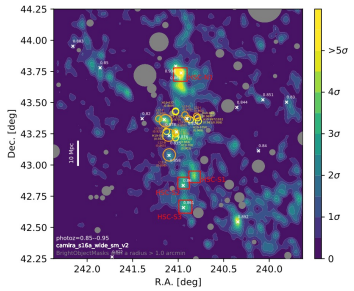
Z=0.36



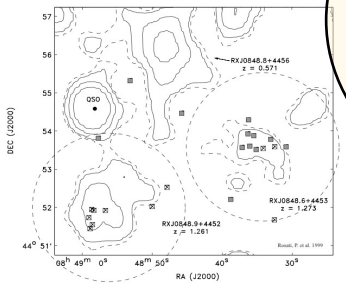
Z=2.45



Z=1.75



Z=0.9



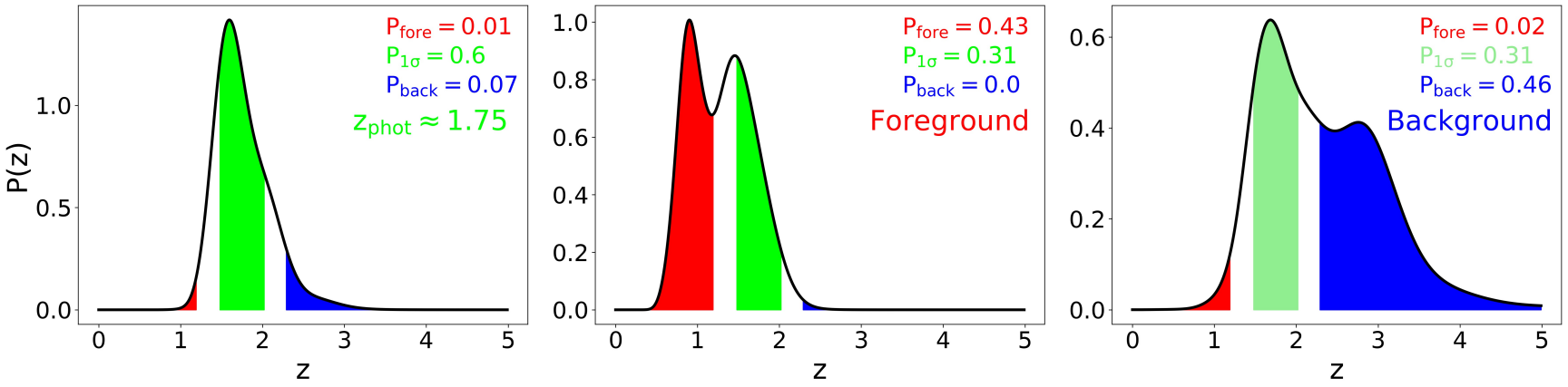
Z=1.3

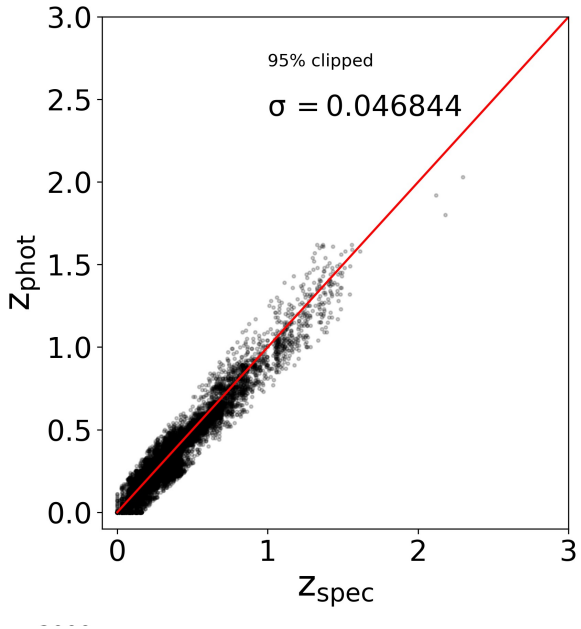
Image Credit: NASA, ESA, and the Hubble Heritage Team (STScI/AURA)

Search for Overdensities using Dust-Obscured Galaxies (DOGs) as Signposts ?

Selection of Galaxies at z = 1.75:

- Improved photometric redshift using 13 band photometry : U + B, R, I + zYJHKs + IRAC (3.6, 4.5, 5.8, 8.0 micron)
- 4.5 μm-selected galaxies at z = 1.75 from SDWFS (Spitzer Deep, Wide Field Survey in Boötes)



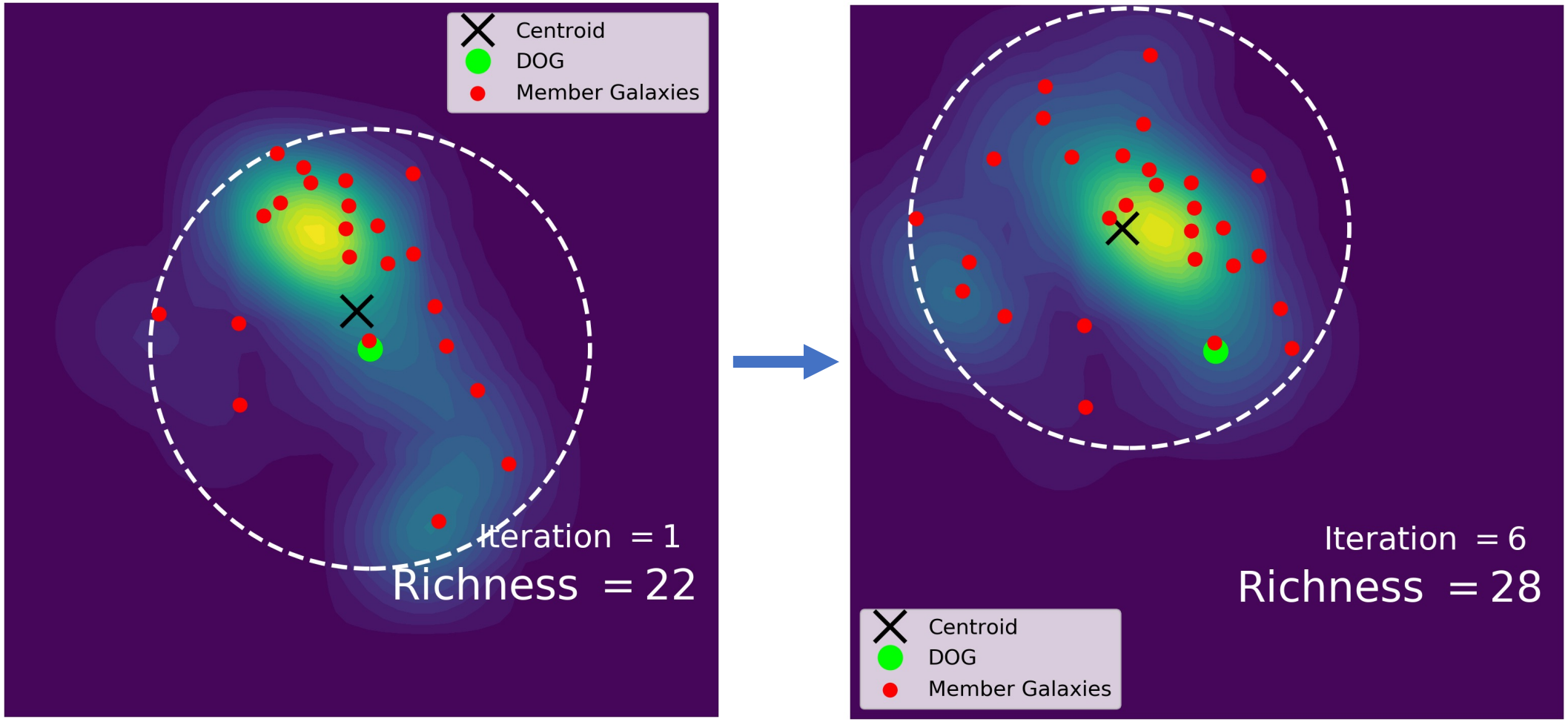


$$P_{1\sigma} = \int_{z_s-0.10(1+z_s)}^{z_s+0.10(1+z_s)} P(z)dz \geq 0.3 \quad \text{where } \sigma \approx 0.10 \; at \; z_s = 1.75$$

1. Search for overdensities in the photo-z Galaxies at z=1.75 using DOGs as signposts.

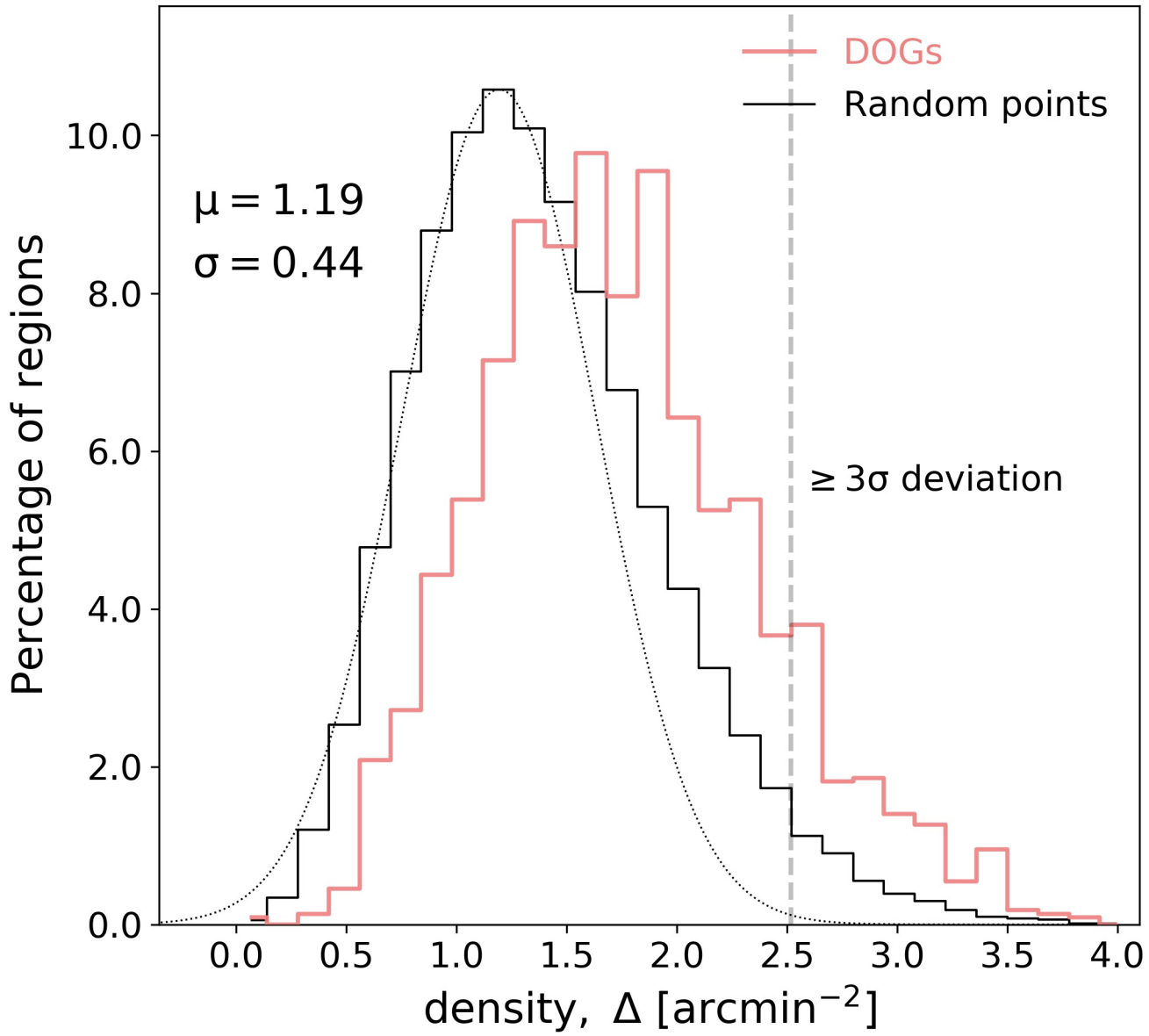
2. We used the full PDF of the photo-z to determine its redshift. **~40000 galaxies are found to be consistent with z=1.75 over the entire field of Boötes**

Search for Overdensities using Dust-Obscured Galaxies (DOGs) as Signposts ?



Smoothed IRAC 4.5 μm flux-weighted map of the SDWFS galaxies near the signpost at z=1.75

Search for Overdensities using Dust-Obscured Galaxies (DOGs) as Signposts ?



- Surface densities of photo-z selected galaxies near DOGs at z = 1.75 in 1.5 arcmin (~ 2 cMpc) search radius.
- Surface densities of the galaxies at z = 1.75 is also measured around a population of randomly dropped points.
- Overdense regions near the DOGs are defined as $\geq 3\sigma$ deviation from the Gaussian fit to the random expectation.