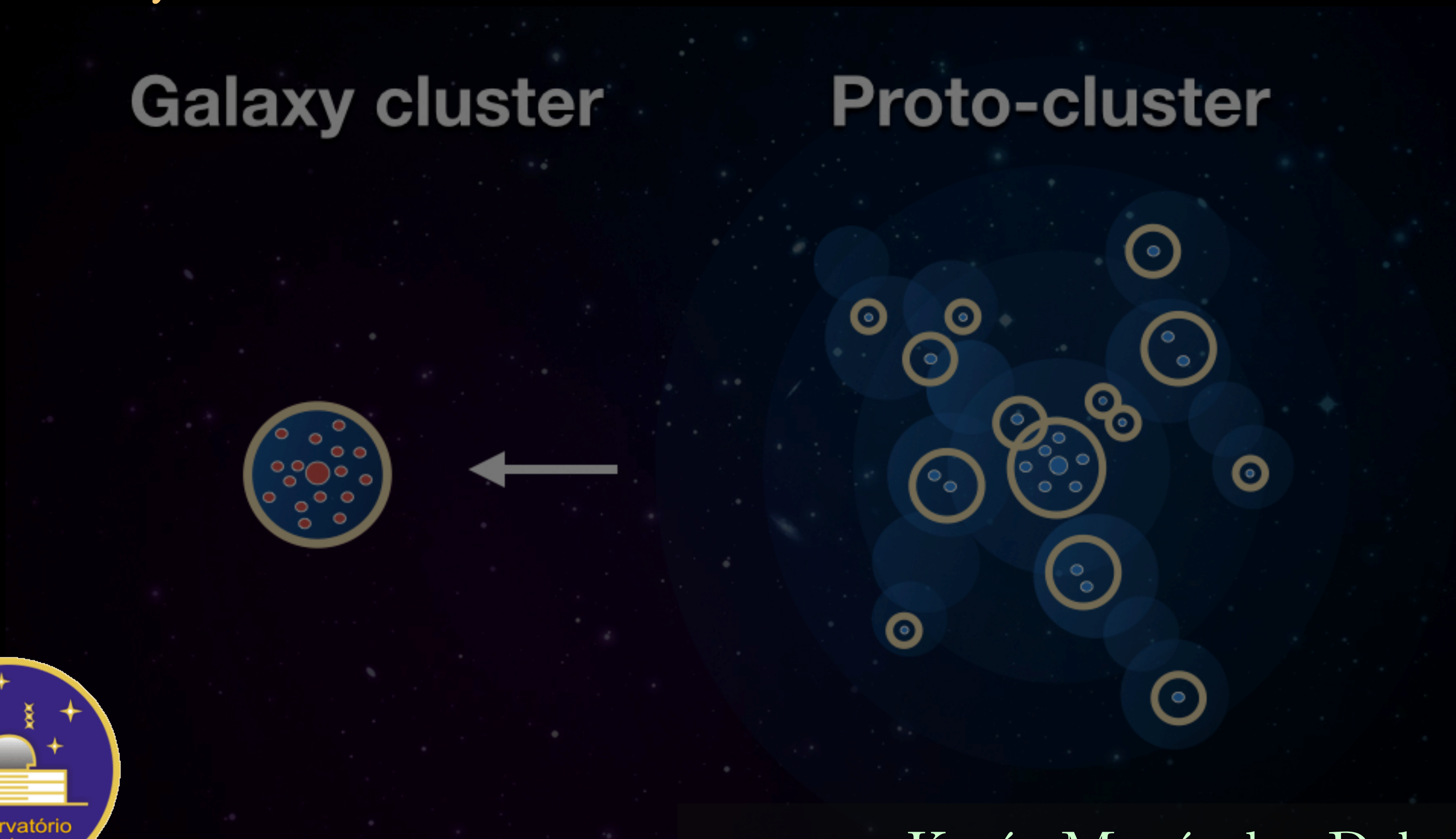
Protoclusters and the Establishment of the Galaxy-Environment Relation



Toy model (Yi-Kuan Chiang, U. Texas)

Observatório do Valongo

Universidade Federal do Rio de Janeiro

Karín Menéndez-Delmestre
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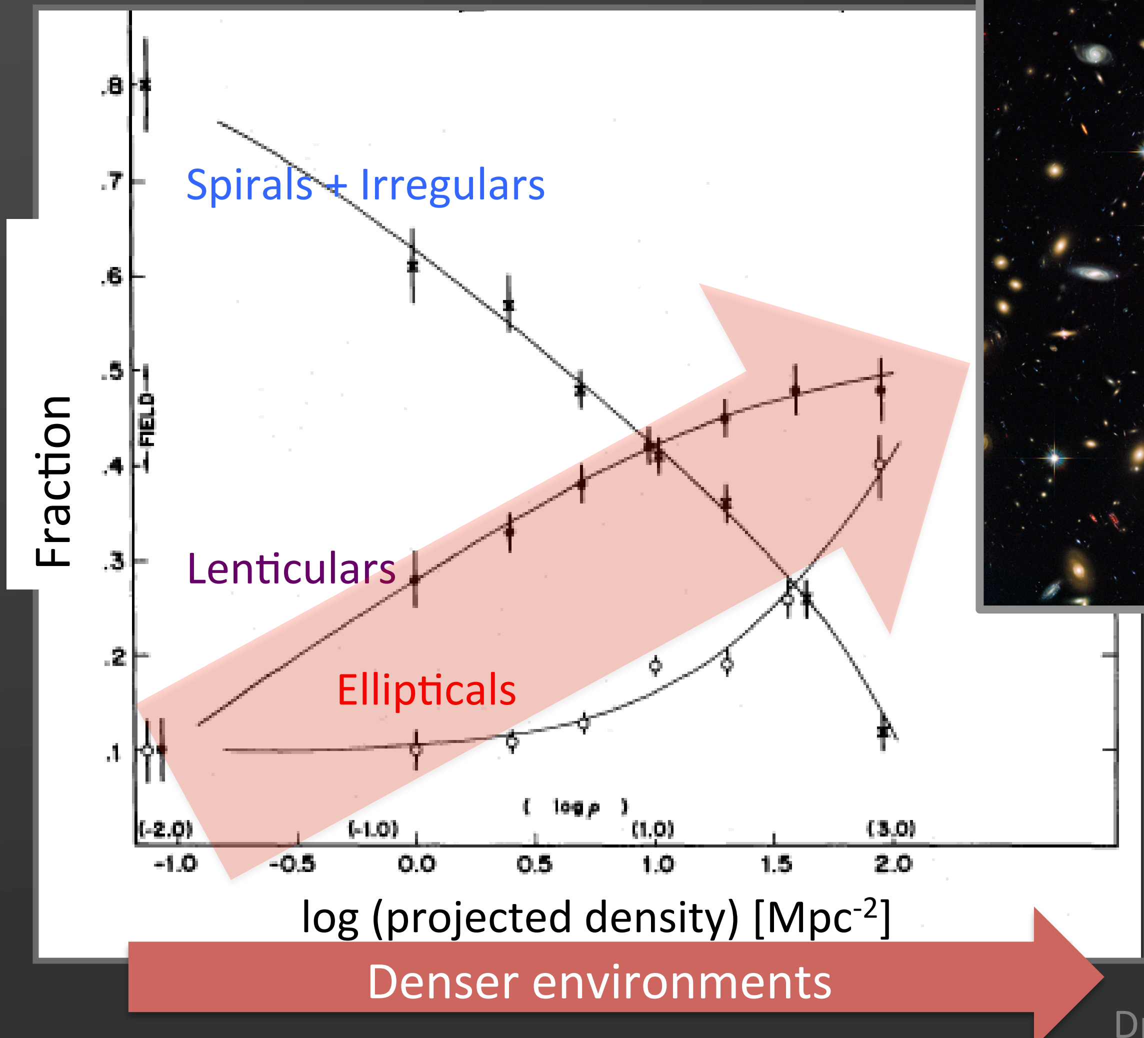
Galaxy properties are connected to the environment

- Morphological segregation



Dressler+80

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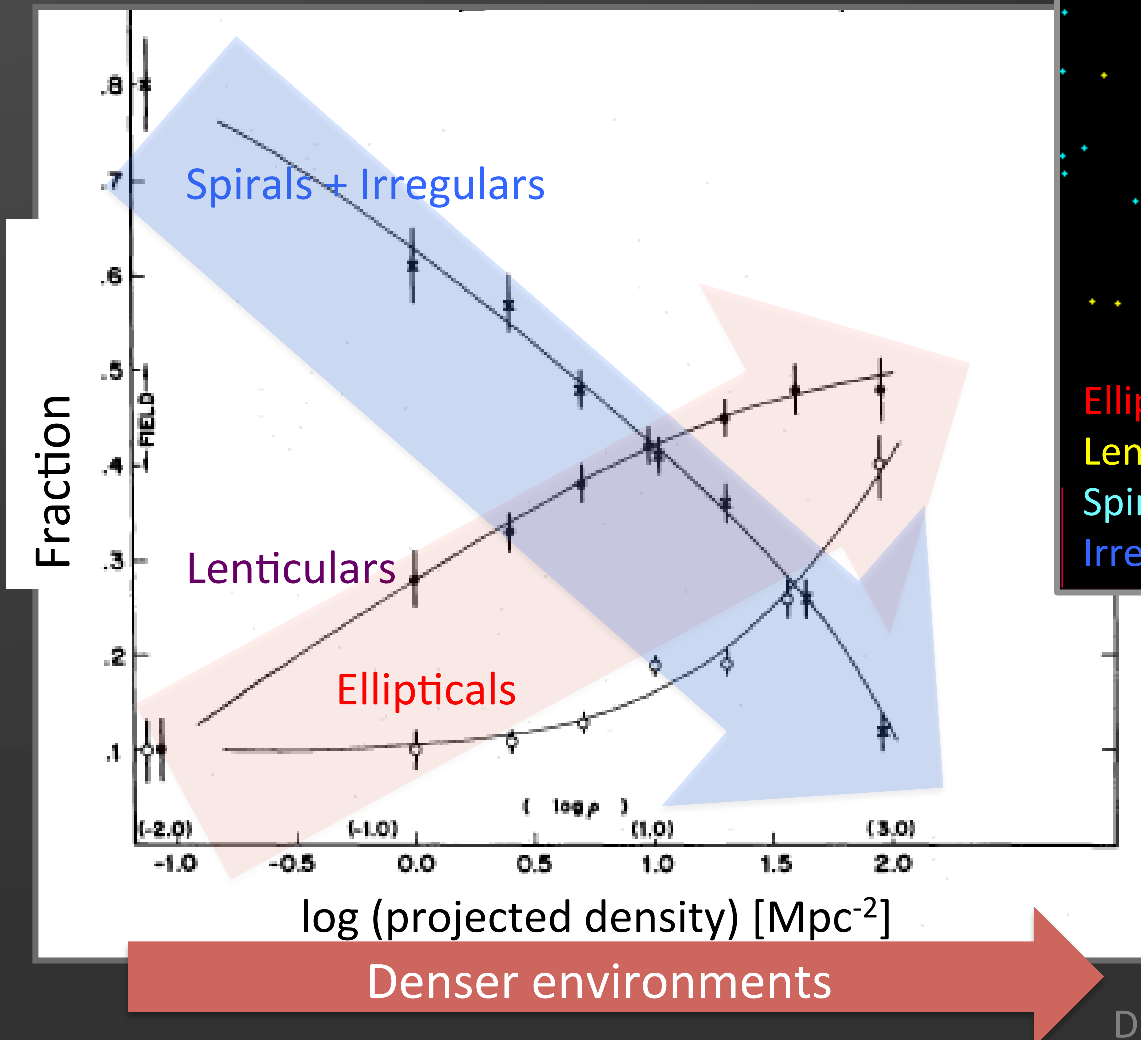

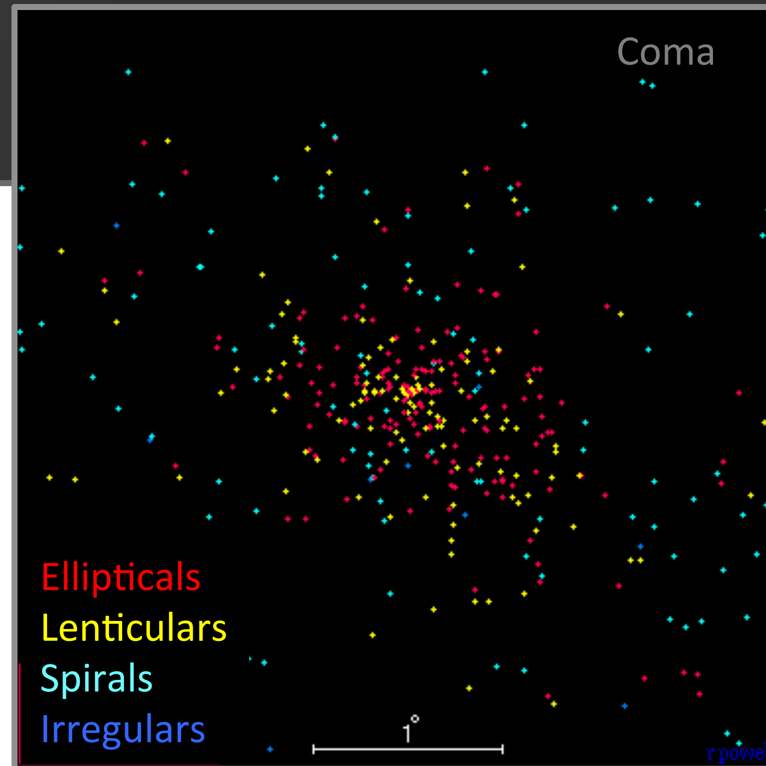

Fraction of spirals (star-forming galaxies) decreases with increasing galaxy number density

Dressler+80

What's the origin of the galaxy-environment relation? Nature or Nurture? (that is the question…)

Nature?

- The environment establishes different initial conditions for different galaxies
- Galaxies are intrinsically different from the beginning
- The formation of ellipticals occurs at high-z in the densest regions

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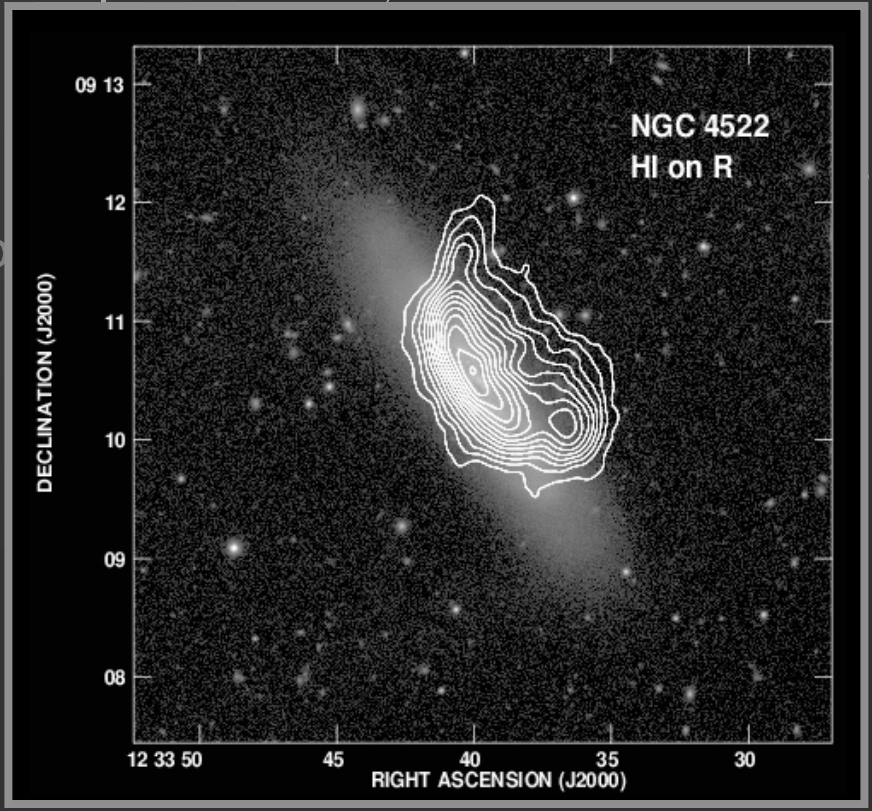

Kenney et al. 2003

Nurture?

- Galaxies follow different evolutionary paths, depending on their local environment.
- Dense environments transform actively star-formging galaxies into more quiescent galaxies via interactions and removal of gas

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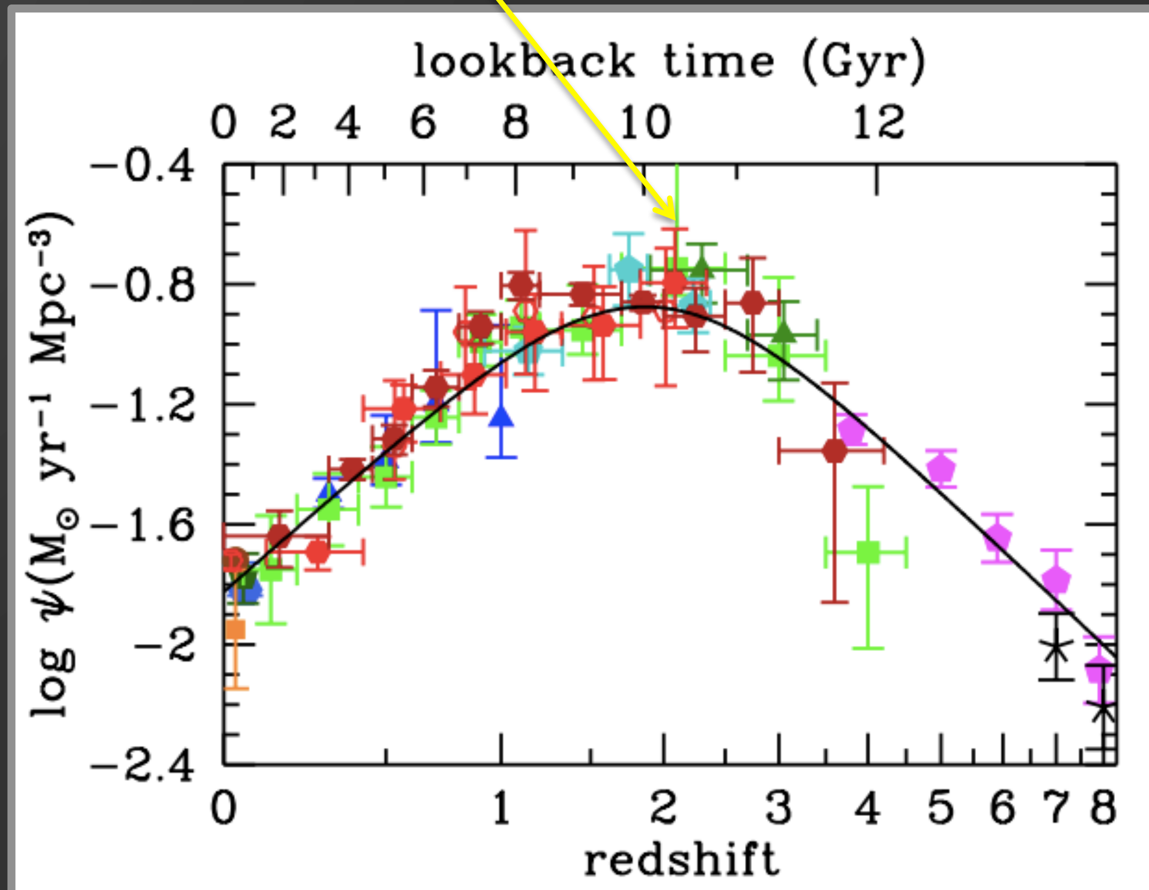
BOTH?

- There are isolated galaxies with low star formation rates

  → the environment is not the only determinant!

What's the origin of the galaxy-environment relation?

- Need to look back at the peak epoch of galaxy formation, where initial conditions likely set the stage for the establishment of the galaxy-environment relation.



Outstanding challenges remain to identify and characterize overdense regions in the distant universe.

Madau & Dickinson 2014

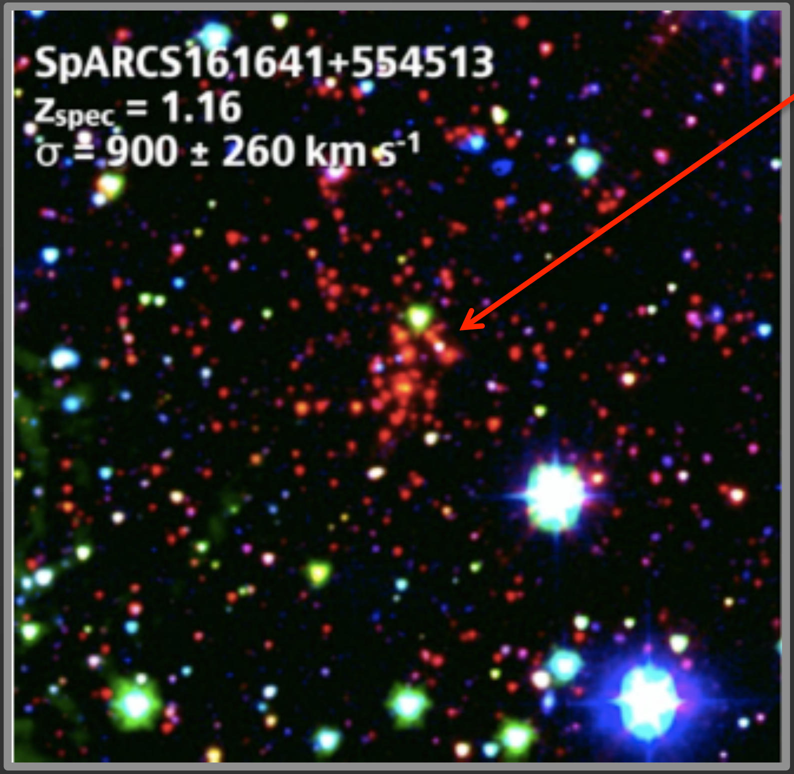
How to identify galaxy-overdense regions?

At low redshift:

① Galaxies

- Optical/near-IR/mid-IR: look for the red sequence in already-established clusters

(Gladders & Yee 2000)



SpARCS collaboration

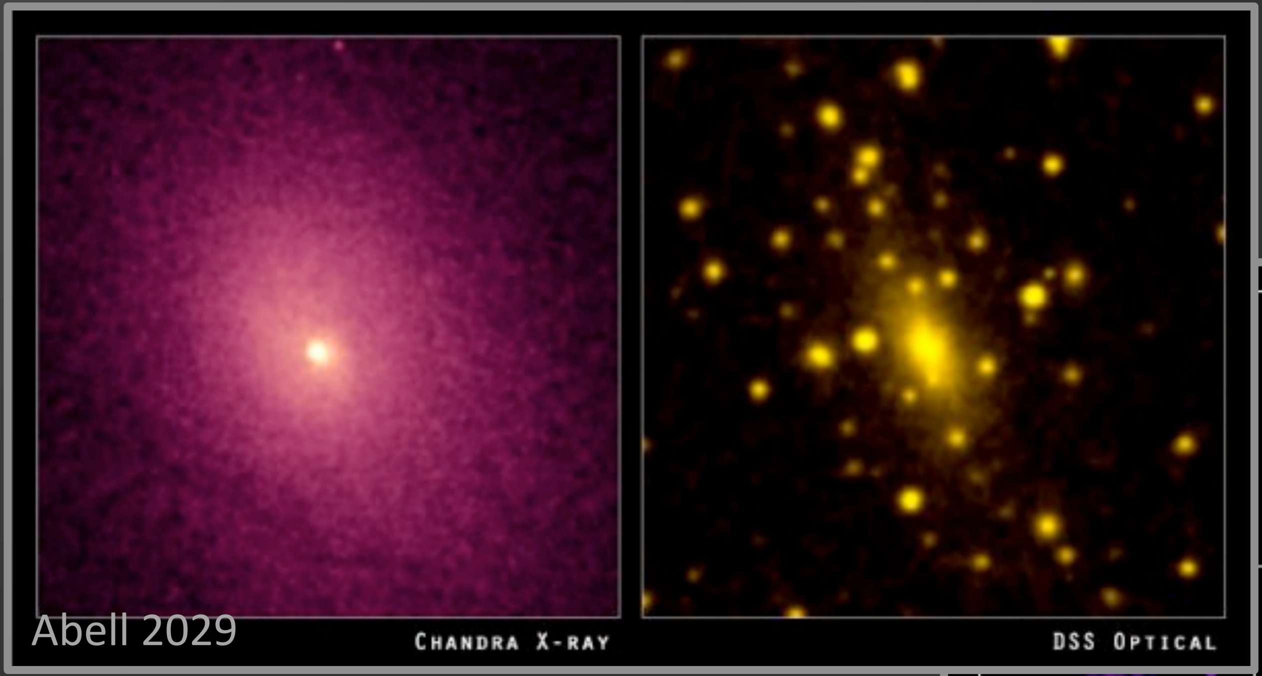
How to identify galaxy-overdense regions?

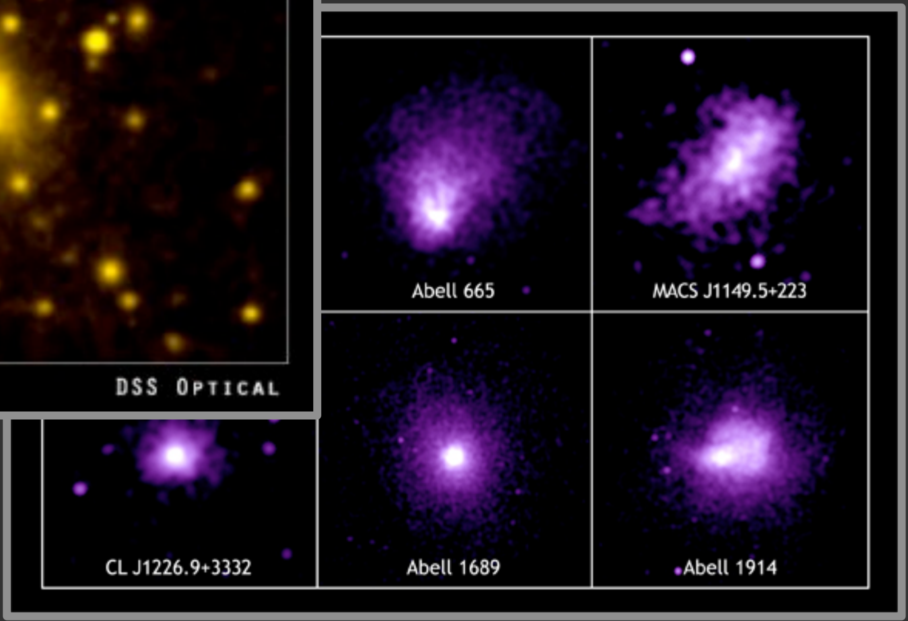
At low redshift:

① Galaxies

② Gas

– X-ray: trace the hot intracluster gas (e.g., Chandra, XMM)





Chandra images
Credit: NASA/CXC/MSFC/M.Bonamente et al.

How to identify galaxy-overdense regions?

At low redshift:

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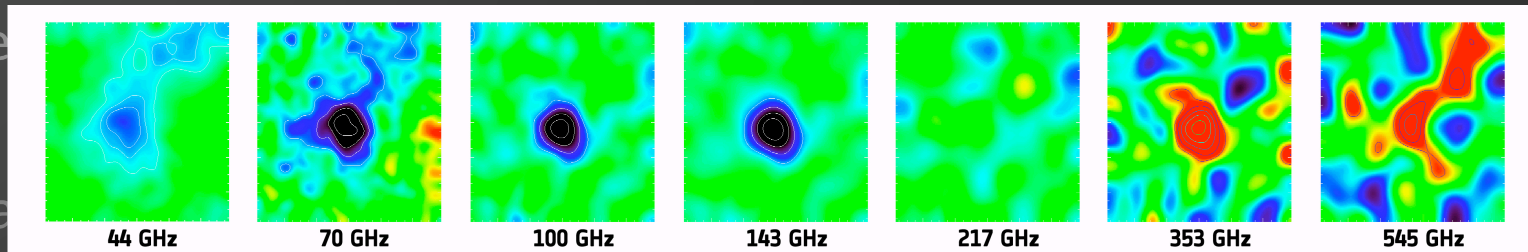
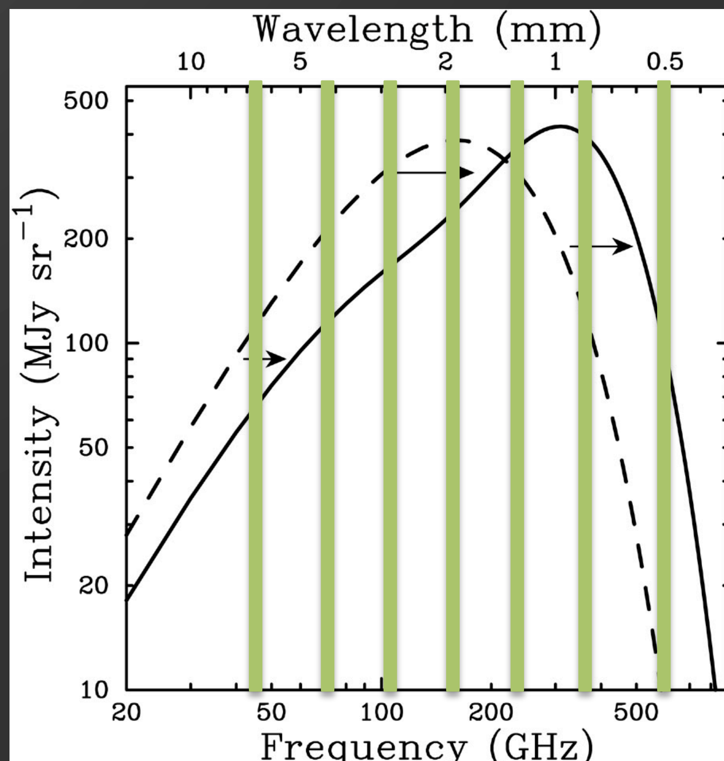
– X-ra

Abell 2319 Planck/ESA



– Sunyaev-Zeldovich effect using CMB experiments (SPT, ACT, Planck)



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③ Gravitational lensing

– Currently expensive, but, e.g., ESA's Euclid mission, ~2020

NASA/ESA

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No perfect approach... out to z~1-2

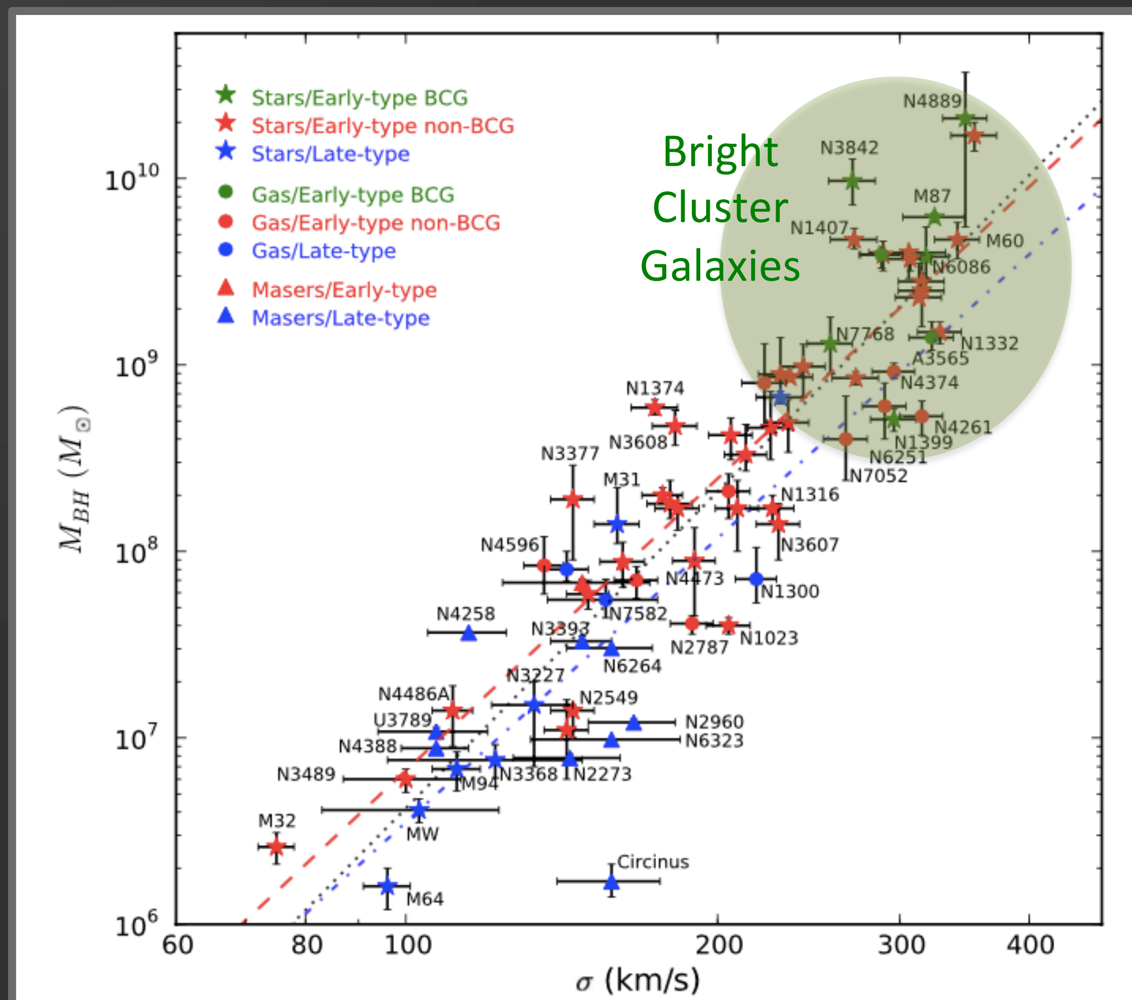
(though extending further with follow-up of SZ-detections)

By the nature of these techniques, (most of) of these clusters are already "formed"

Protocluster tracers at higher redshifts

- Radio galaxies and quasars have been used to map the large scale structure at z ~ 2-5 (e.g., Venemans+02, Kurk+04, Overzier+05)

Largest black holes (and biggest galaxies) at high redshift, so likely progenitors of BCGs!



McConnel & Ma 2013

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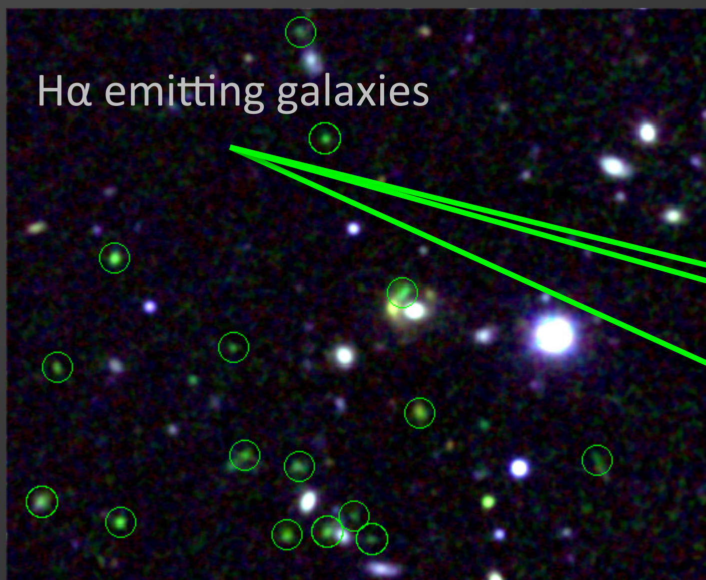

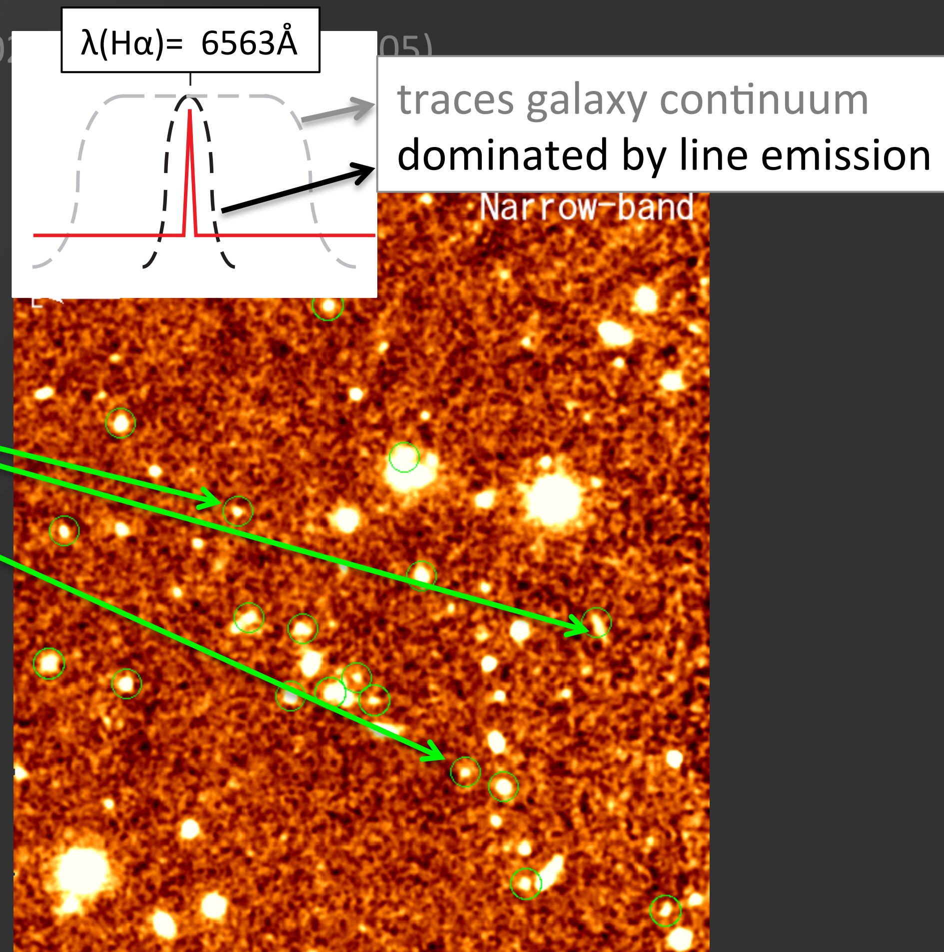

Approach:
Look for "more normal" galaxies in the vicinity of these tracers

Protocluster at z~2.2 around radio galaxies with Subaru Telescope (Shimakawa+14)

Protocluster tracers at higher redshifts

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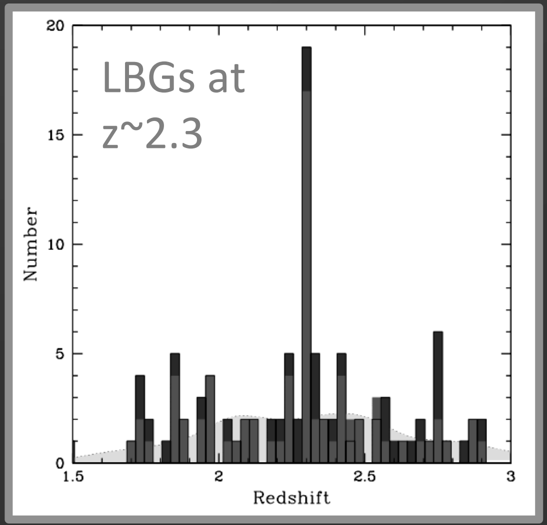
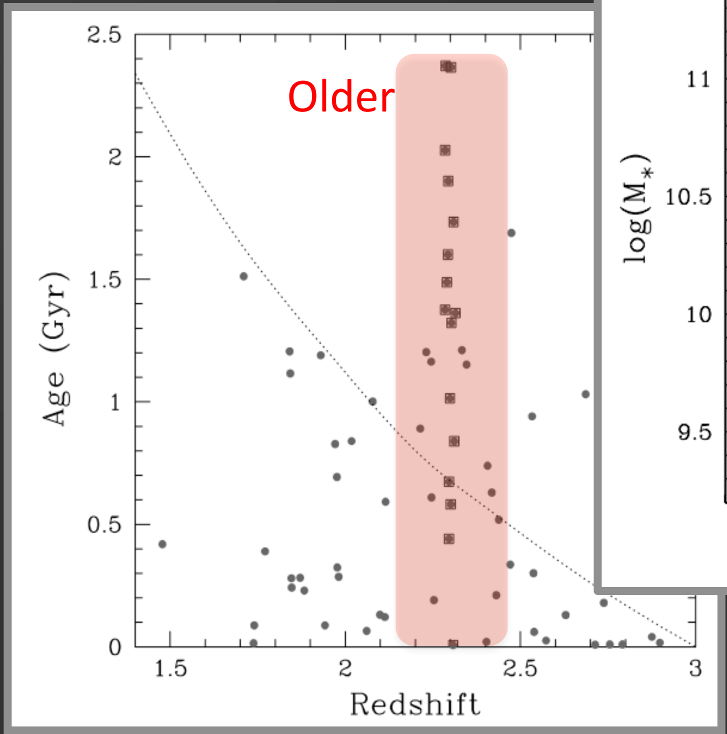
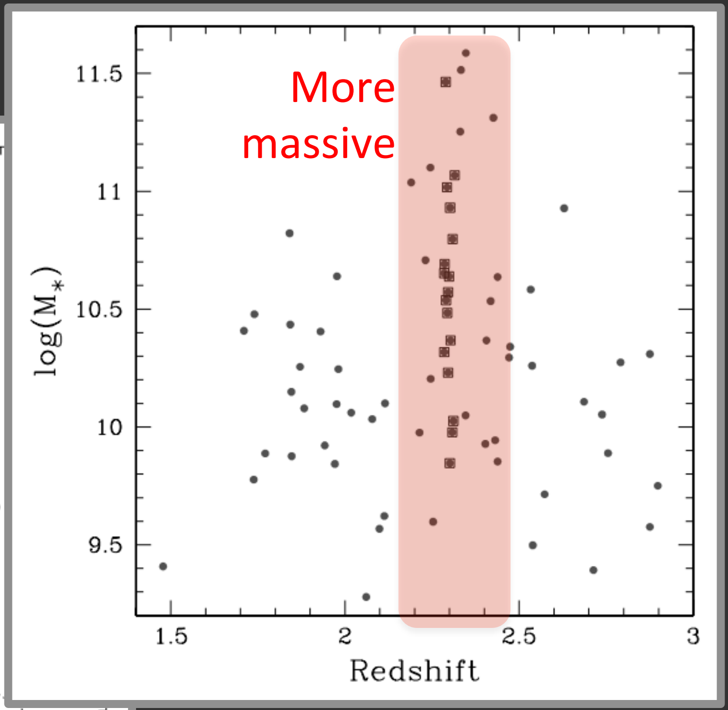
- Protocluster galaxies are already more evolved than those in the field → accelerated formation in dense regions

Already evidence for enhanced evolution







Steidel et al. 2005

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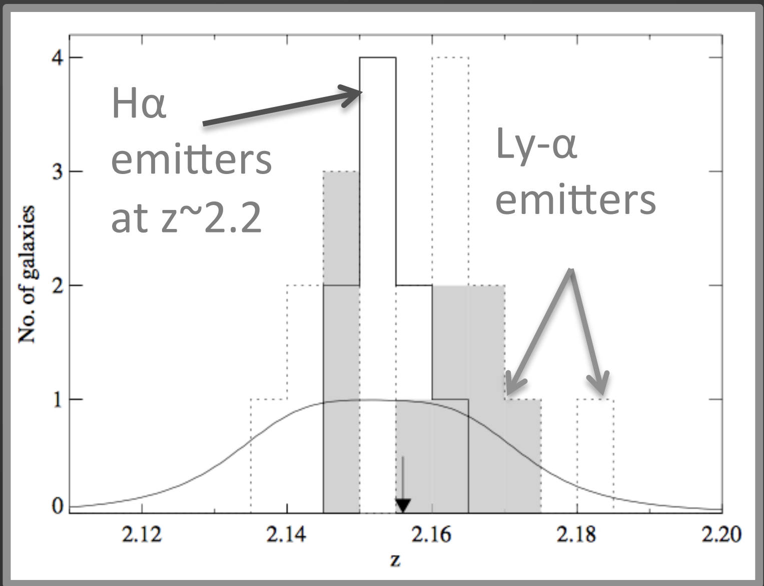
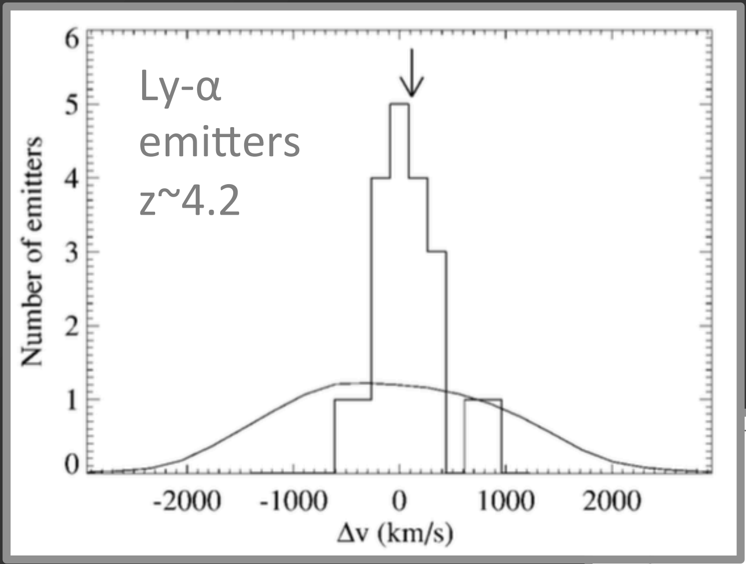
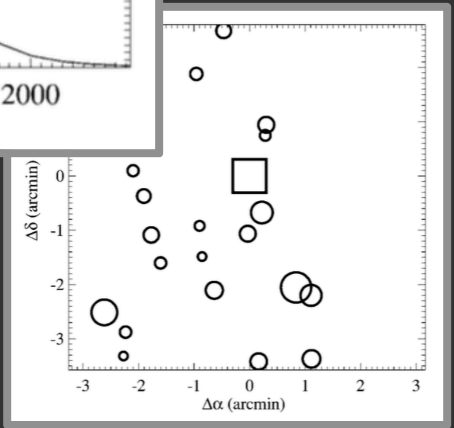
Quite successful approach



Kurk+04

Around
radio galaxy
PKS 1138-262





Around
radio galaxy
TN J1338-1942

Venemans+02

Protocluster tracers at higher redshifts

- Radio galaxies and quasars have been used to map the large scale structure at $z \sim 2\text{-}5$ (e.g., Venemans+02, Kurk+04, Overzier+05)
- Protocluster galaxies are already more evolved than those in the field → accelerated formation in dense regions

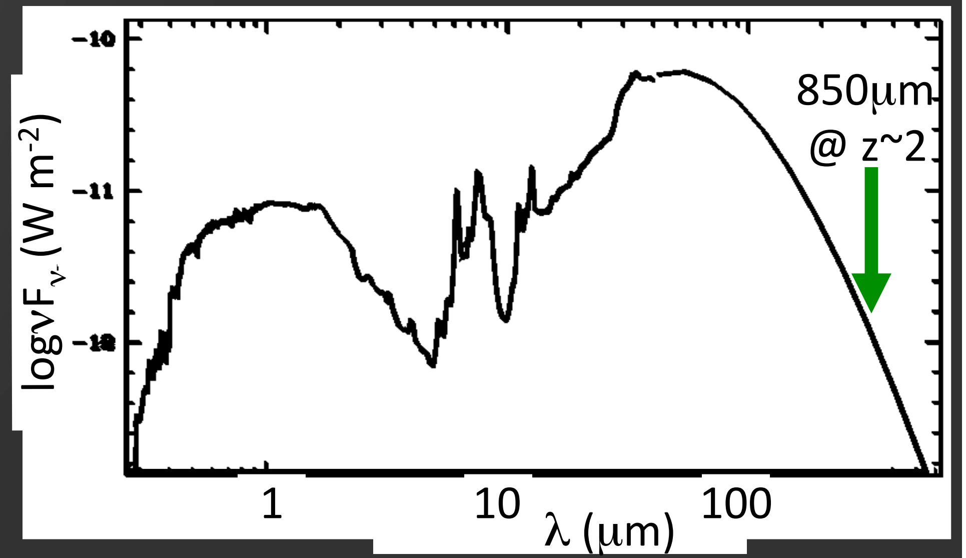
<u>HOWEVER:</u>

1. These tracers represent a short stage in the life of a galaxy ($\sim 10^7$ years)
2. Radio fluxes drop with redshift
   - strong observational bias towards more evolved structures

Many additional forming clusters… We need more abundant (somewhat less extreme) tracers!

High-Redshift Ultra-luminous Galaxies – untapped tracers of large-scale structure

- More abundant than QSOs by a factor of ~5-10 (Chapman+03+05, Coppin+06)
  - Submillimeter-selected ULIRGs



Kennicutt+03

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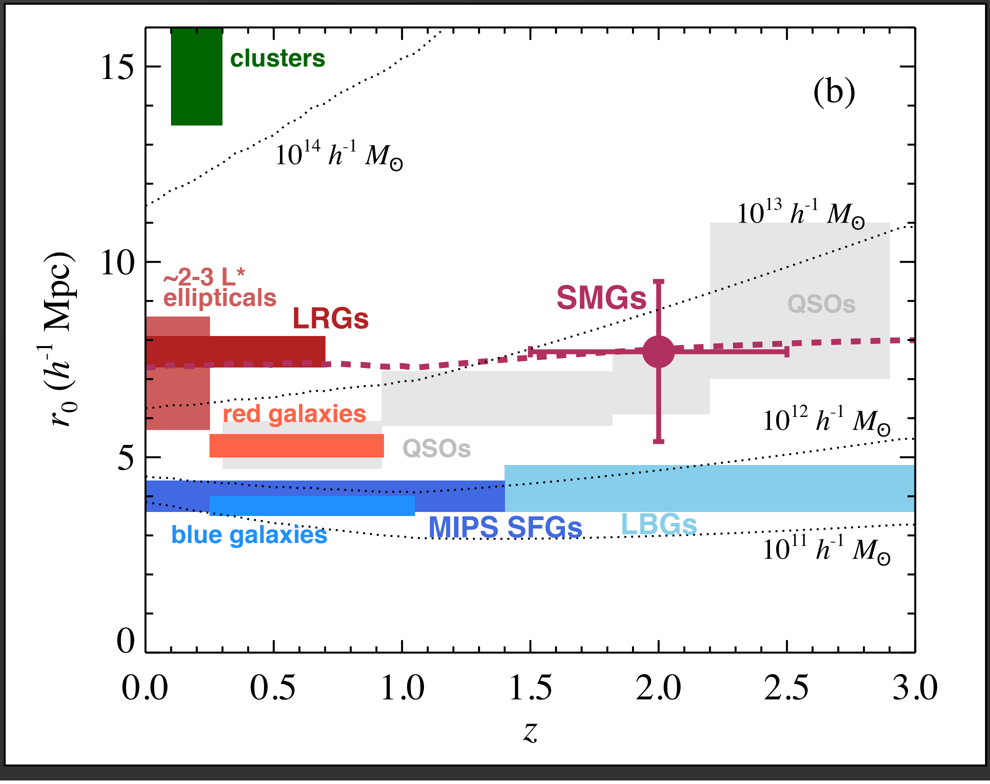
  Submillimeter-selected ULIRGs (Chapman+03+05, Coppin+06)

- SMGs and QSOs at z~2 live in DM halos of similar mass ($M_{halo} \sim 10^{13}\ M_{\odot}$)
  - more clustered than other high-z populations (e.g., Lyman-Break Galaxies; Steidel et al.)



Hickox+12

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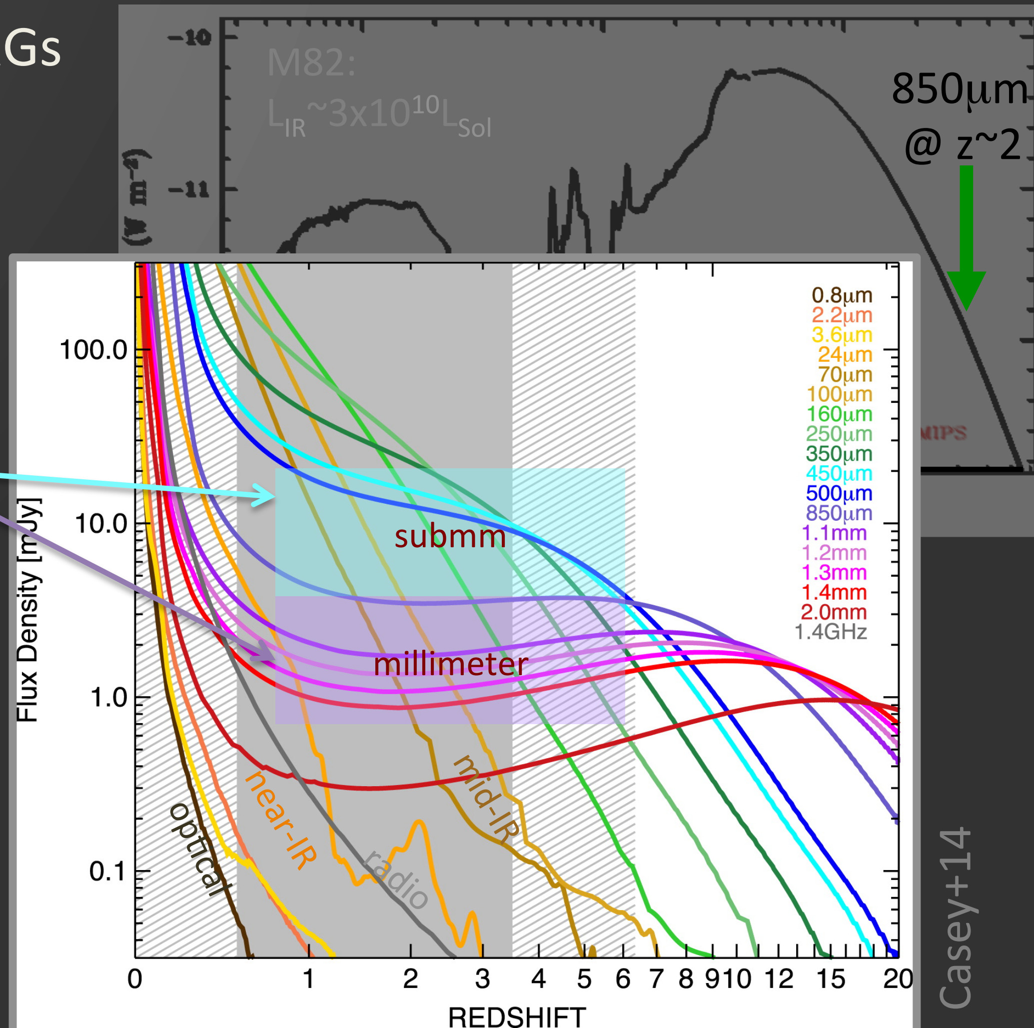
<u>Why is the submm selection so special?</u>

- "Normally", the further a galaxy is, the fainter it appears
- (negative) K-correction in the submm/mm beats the odds!
  - As we search for galaxies further and further away, the submm/mm flux stays approximately the same!

SMGs are just as submm-bright at z~1 as they are at z~5 → key to inspect the very distant universe!



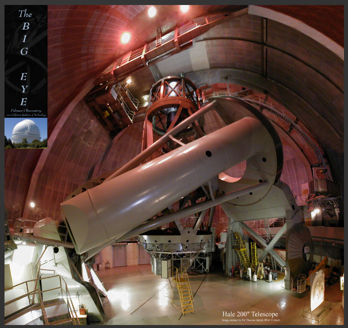
Submm Galaxies: Signposts of Protoclusters

(an on-going investigation…)

Co-Is: Peter Capak (Caltech, EUA), Andrew Blain (Leicester, UK), Kartik Sheth (NRAO, EUA), Thiago S. Gonçalves (Valongo/UFRJ), Claudia Scarlata (U. Minnesota, EUA), Aldée Charbonnier (Valongo/UFRJ), Harry Teplitz (Caltech, EUA), Paulo A. Lopes (Valongo/UFRJ)

Keck LRIS

Palomar LFC



Magellan IMACS

Submmm Galaxies: Signposts of Protoclusters

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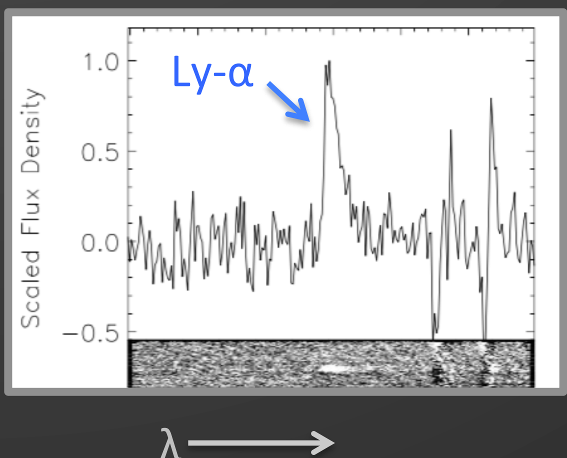
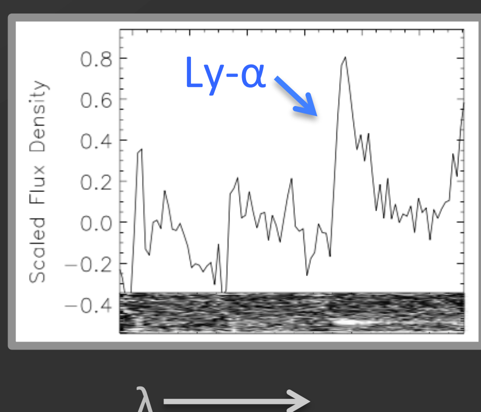
- We target candidate overdensities at z~1-5

  > 4 Gyr during which a protocluster slowly approaches virialization

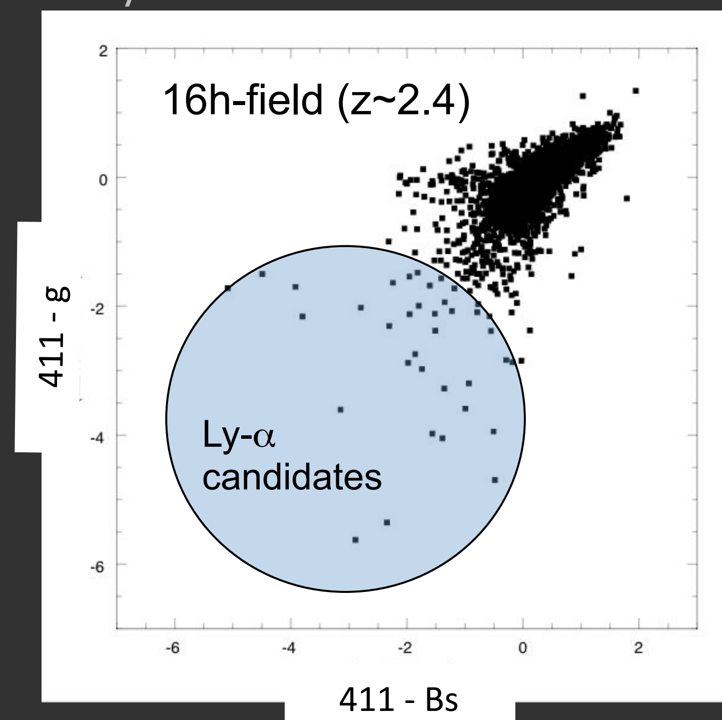
Steps

1 Identification of overdensity members





Narrow-band selection of Lyα emitters



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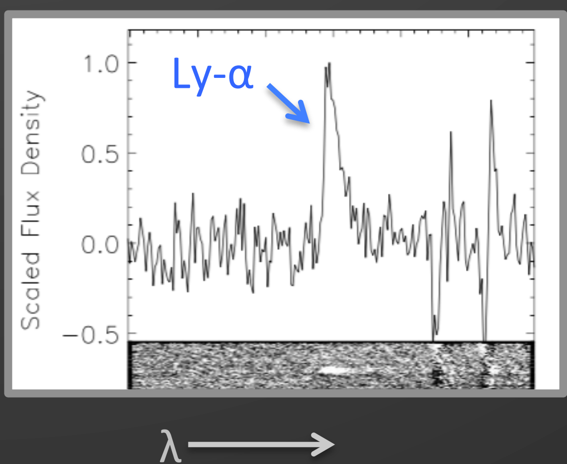

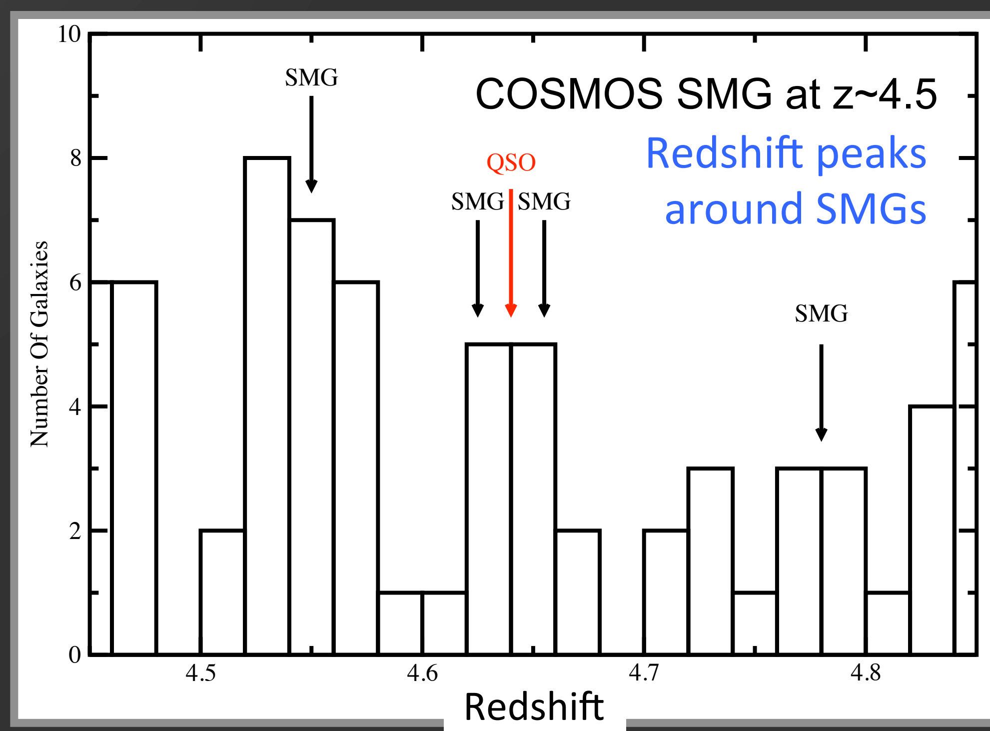

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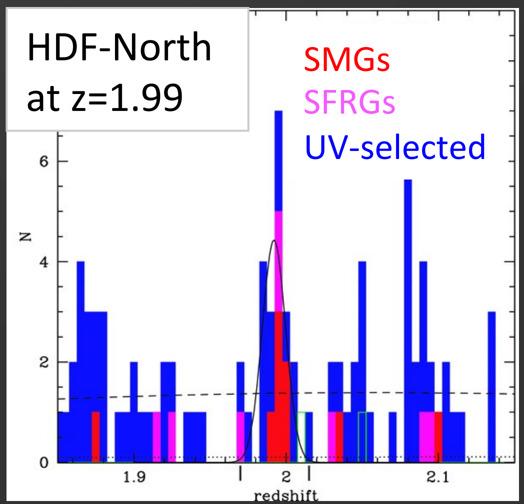
Steps

① Identification of overdensity members

② Characterization of overall significance of the overdensity

- use studies of Lyα emitters in the field (i.e, outside of overdensity) at similar redshifts as a control comparison

(e.g., Large Lyman Alpha Survey; Rhoads et al. 2000)



Chapman+09

Tracers of halos with more modest masses, caught in an active period

→ SMGs appear to trace a wider range of environments!

Submm Galaxies: Signposts of Protoclusters

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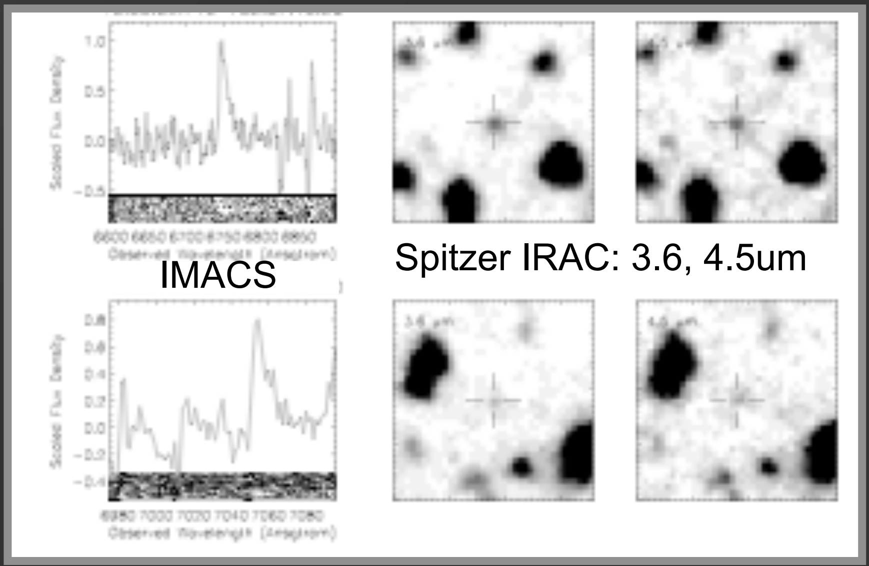
③ Follow-up study of overdensity members to extract individual/stacked galaxy properties, probing for trends in the spatial distribution



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④ Assessment of distribution in galaxy properties according to protocluster maturity (e.g., overdensity mass, gaussianity of the relative velocity of overdensity members)

Take Away Points

- Most massive structures formed over a wide redshift range
  - They are forming their stars/galaxies at z>2
  - Need to probe higher redshifts to trace the origin (and evolution) of the galaxy-environment relation
- Radio galaxies have been successfully used as tracers of protoclusters, but need more abundant tracers at high redshift!
- SMGs appear to be good tracers of overdense regions at z>1
  - tracers of structures with modest masses caught in highly active periods

  → SMGs may be tracers of a wider range of environments beyond the progenitors of todays very rich clusters
- With our program we aim to probe for changes in the distribution of galaxy properties and explore the way galaxy and local environment relate to each other within the broader picture of a cosmologically-evolving overdensity.