Olivier on Environment: The interplay between the growth of structures and galaxies

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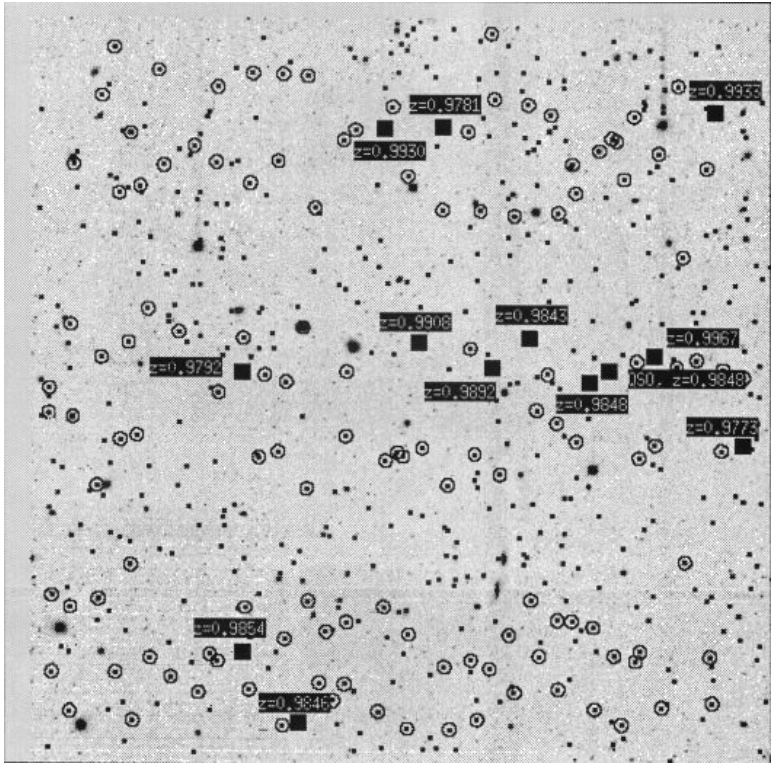
Olivier's early love of galaxy environment:

- Discovery of a high redshift (z~0.98!) cluster:
  - Le Fèvre+94
- Galaxy clustering statistics from the CFRS:
  - Le Fèvre+96
- The role of mergers in galaxy evolution:
  - Le Fèvre+00

Olivier with current IfA director Doug Simons at CFHT in 1994



Le Fèvre+94

Olivier's legacy of environmental studies over three decades (a.k.a the talk outline)

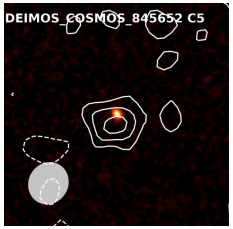
- The many facets of environment (Olivier was interested in many)
  - Introduction
- Slow methodical increase in both the capabilities of the telescopes/instrumentation and the analysis techniques to match the increasing challenges of data of increasing depth and breadth
  - Brief history of environmental studies across four VIMOS surveys
- Keen on interplay with simulations, both from the standpoint of informing simulations and using simulations to contextualize observations (though particularly liked the former and proving simulators wrong).
  - No time for this in this review, feel free to ask if interested!
- At every stage, in every survey, Olivier pushed to maximize the data and was on the leading edge of environmental studies
  - Legacy and collaborations

MAIN GOAL
understand how galaxies assemble their stellar mass across time

Two main channels:

In-situ: SFR

E.g.: isolated starburst, z~5, ALPINE survey (Le Fèvre+20)



Ex-situ: mergers

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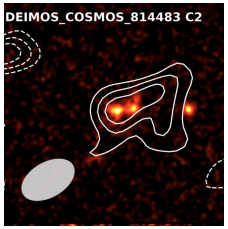
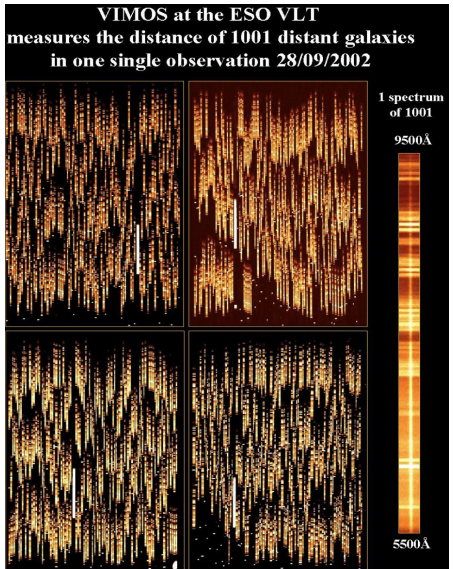


Both depend on specific environments!



BUT, **need incredible datasets** for measuring galaxy properties AND environment of *representative* galaxy populations:

- Spec-z for better environment parameterization

- Wide span in redshift to study evolution over multiple epochs

- Large volumes (dense environments are rare!)

- Deep photometry + spectroscopy to constrain galaxy properties and photometric redshifts

→ need for high-z specz surveys → VIMOS

VIMOS commissioning team at VLT/MELIPAL in 2002 just after first light (credit: ESO)

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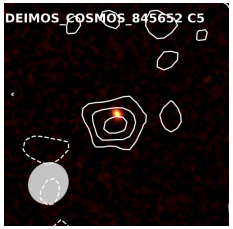

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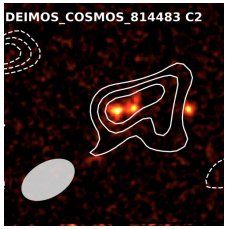

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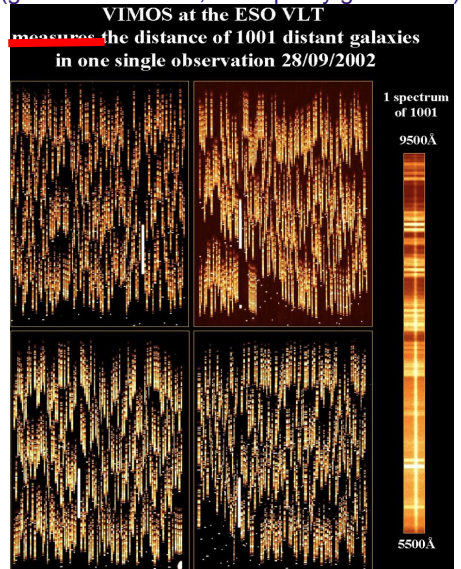
attempts to measure

(got ~600 redshifts, still a pretty good haul!)



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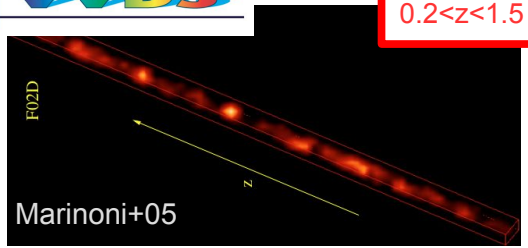
Intermediate- and high-z spec-z surveys with VIMOS

with Olivier's leading and/or contribution

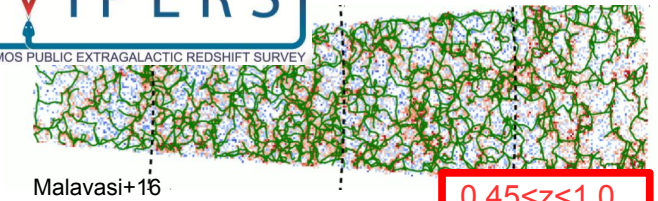
VVDS

0.2<z<1.5



VIPERS

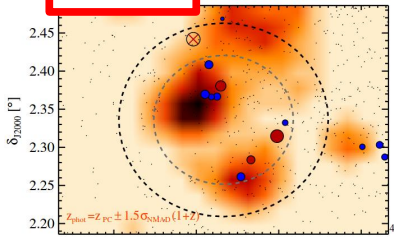
VIMOS PUBLIC EXTRAGALACTIC REDSHIFT SURVEY



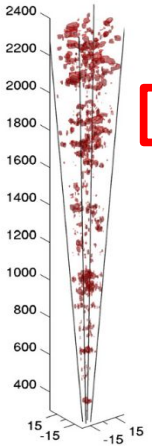
Malavasi+16

0.45<z<1.0

2<z<5.0

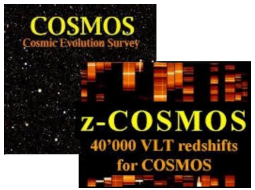


Lemaux+18



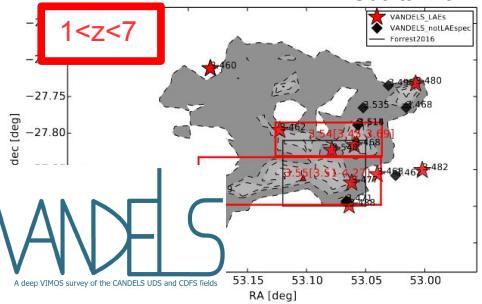
0.2<z<4.0

Kovac+10

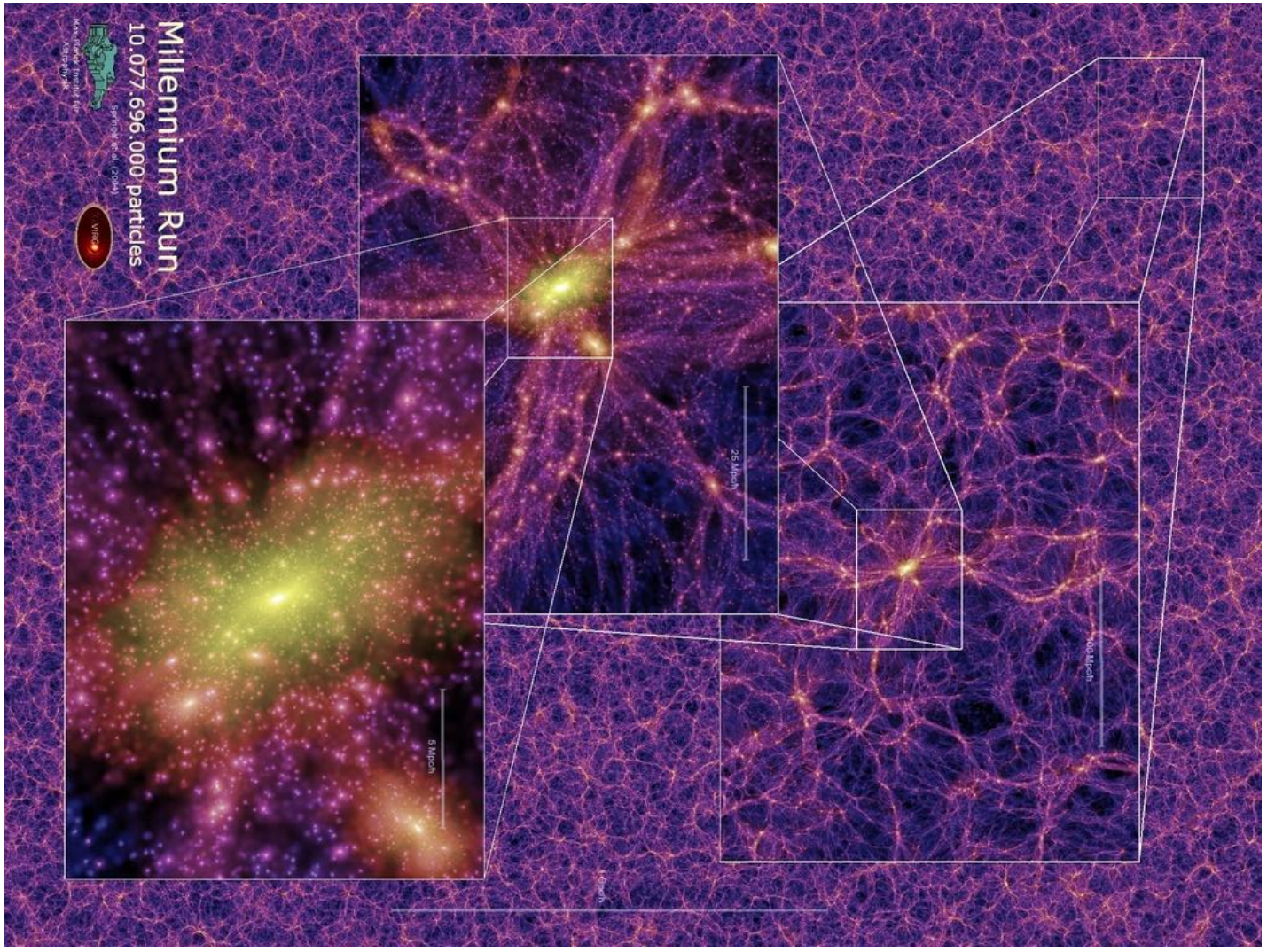


Guaita+20

1<z<7

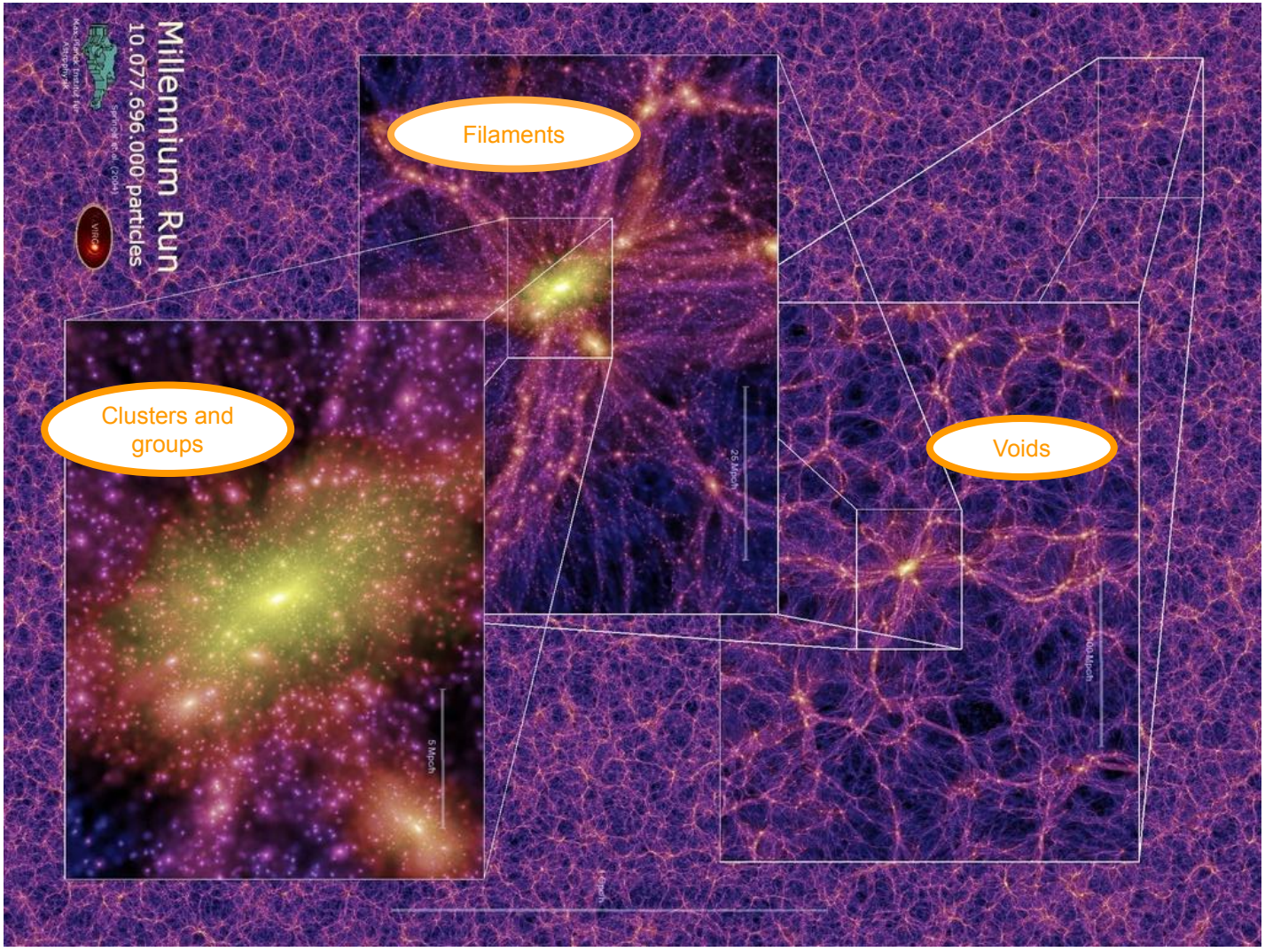


The many facets of environment



The many facets of environment

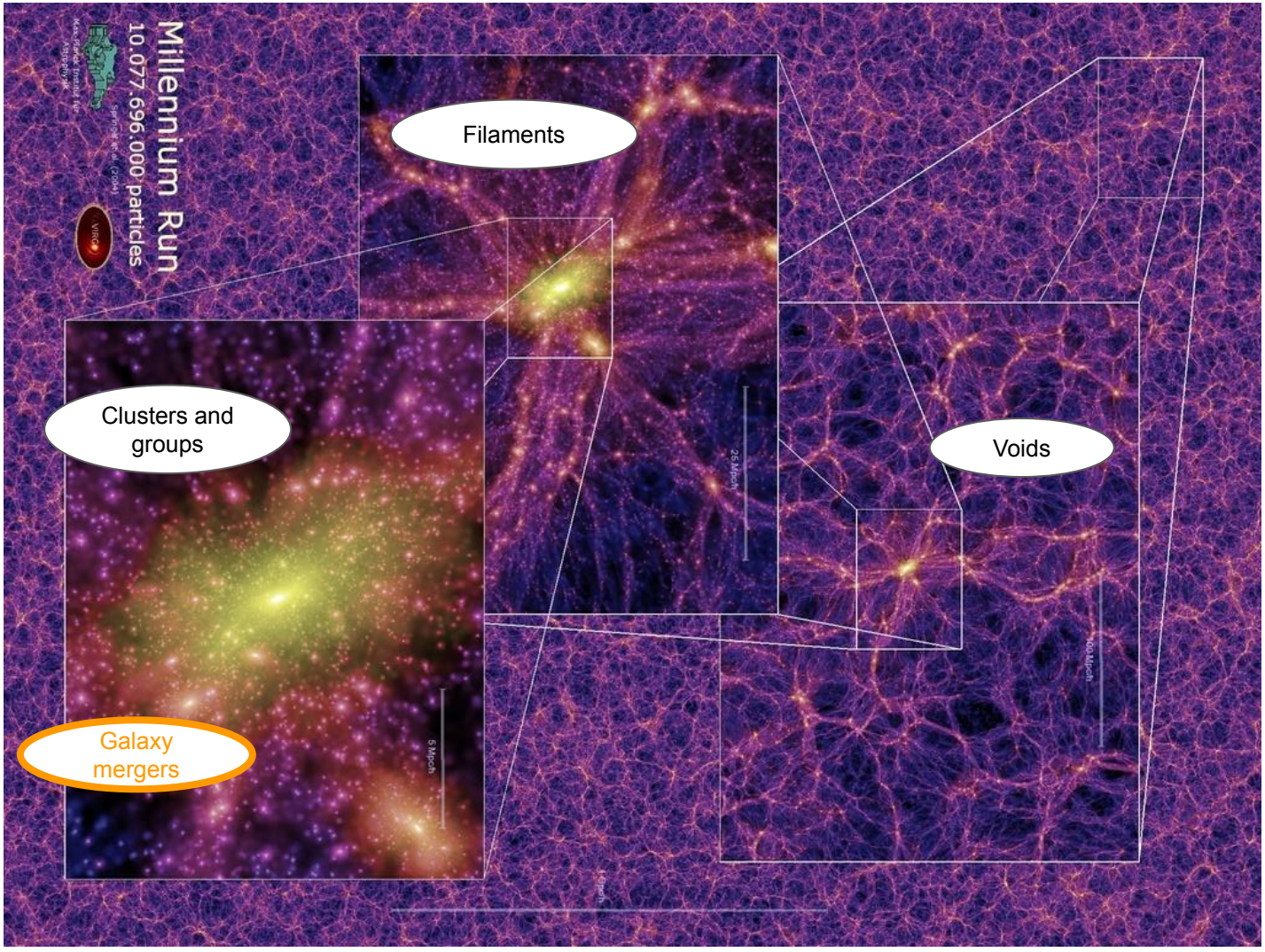
From voids to clusters…



The many facets of environment

From voids to clusters…

.. to the smallest-scale high density environments



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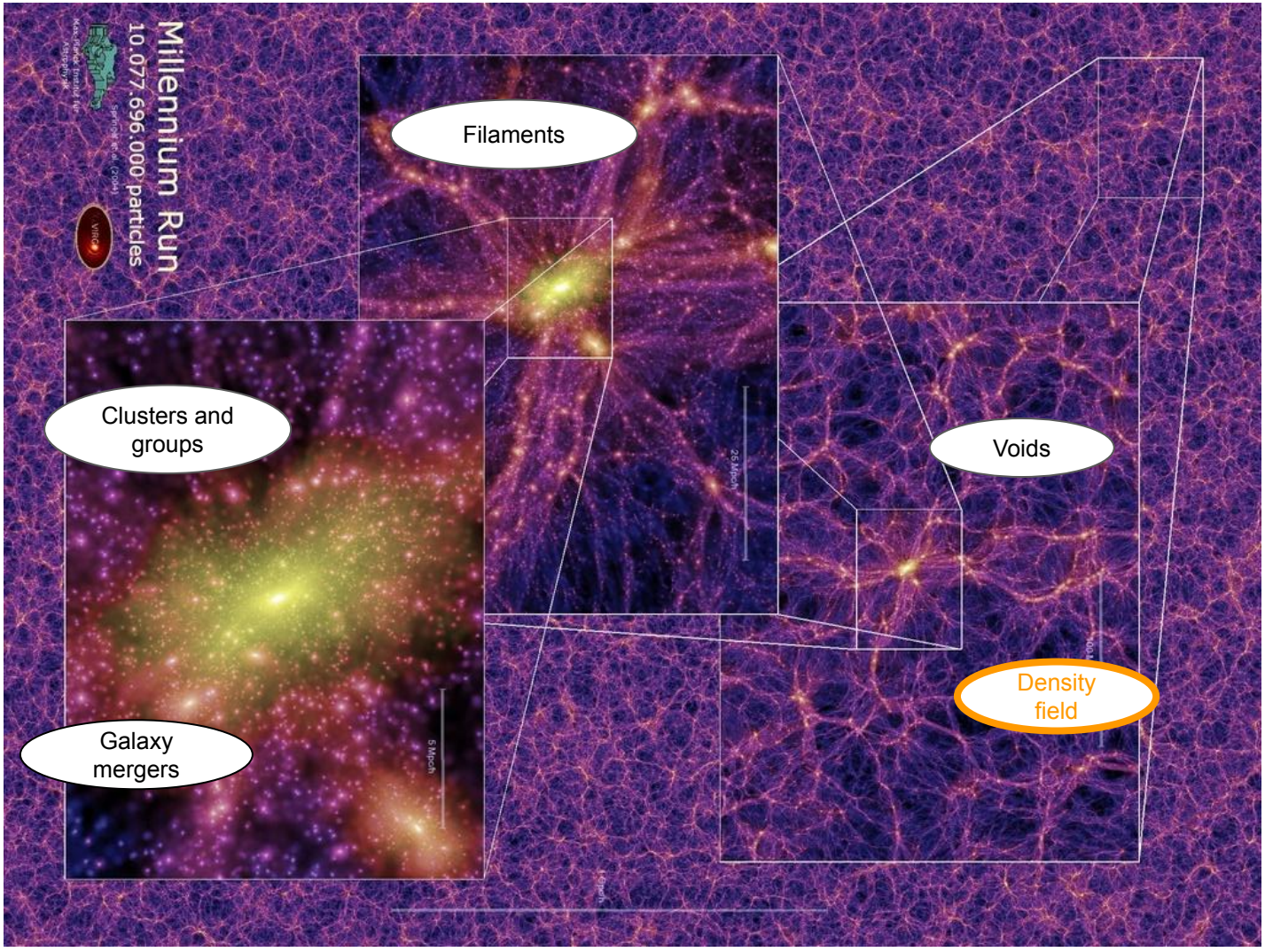
Density field to span the entire range of local environments



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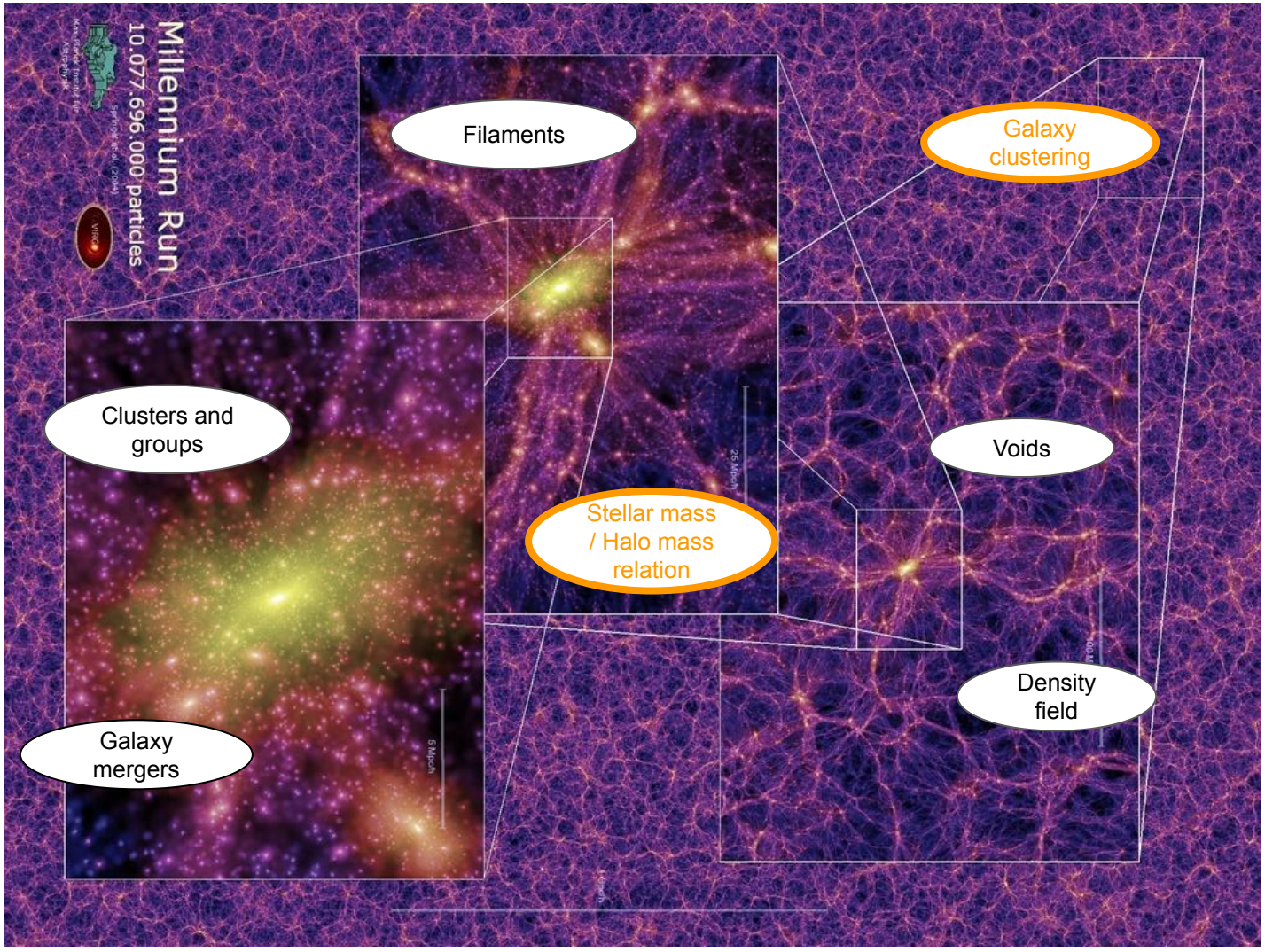
Statistical indicators on how stellar mass traces dark matter



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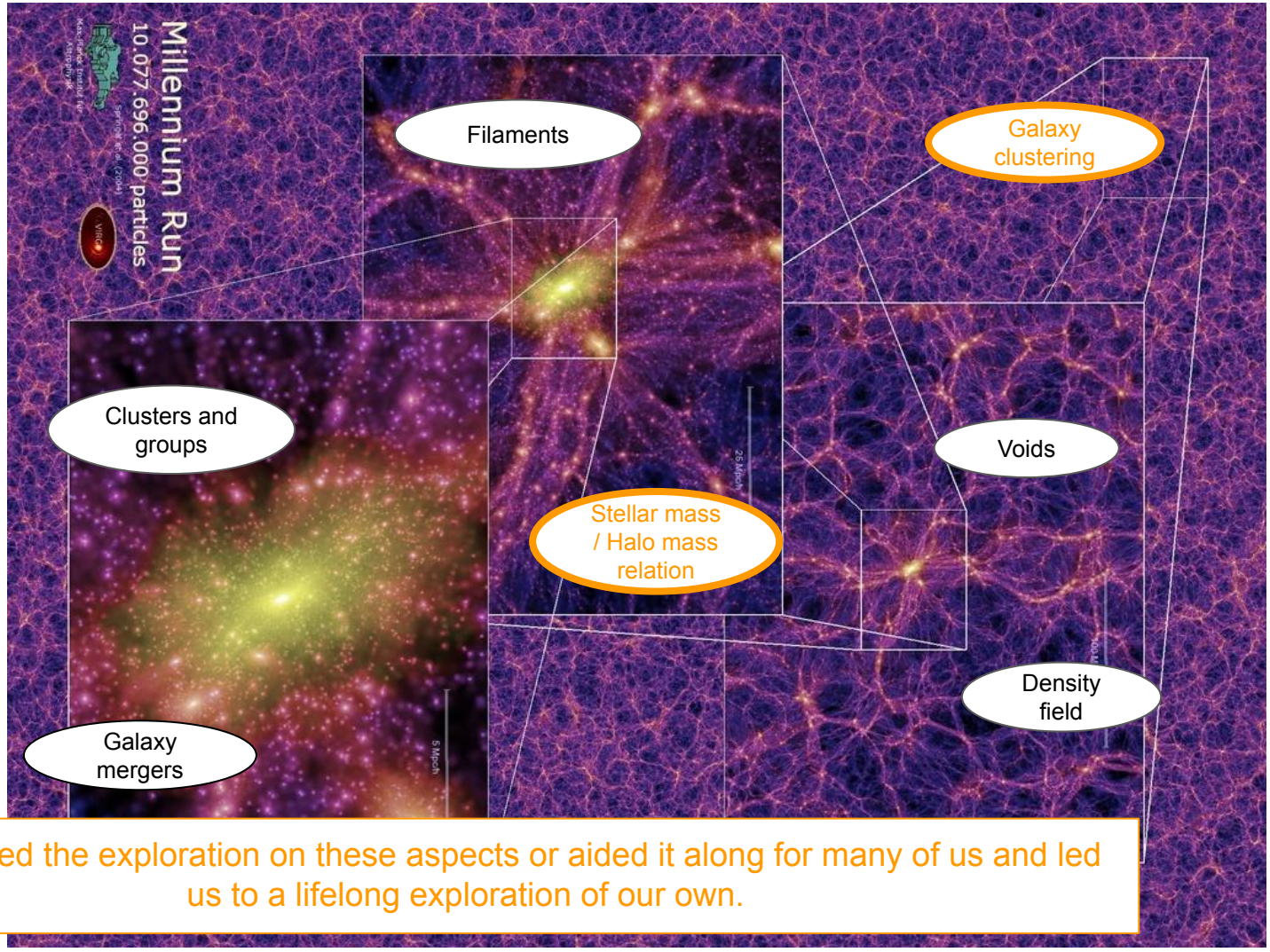
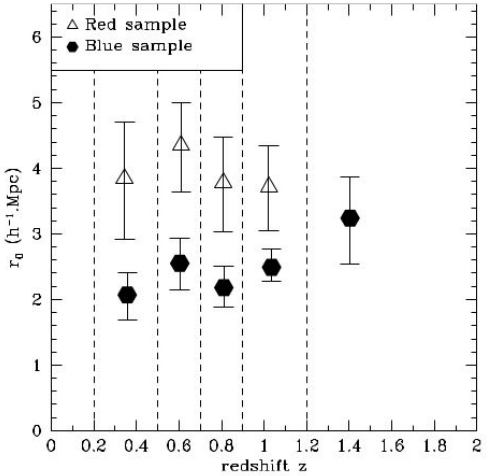


Olivier started the exploration on these aspects or aided it along for many of us and led us to a lifelong exploration of our own.

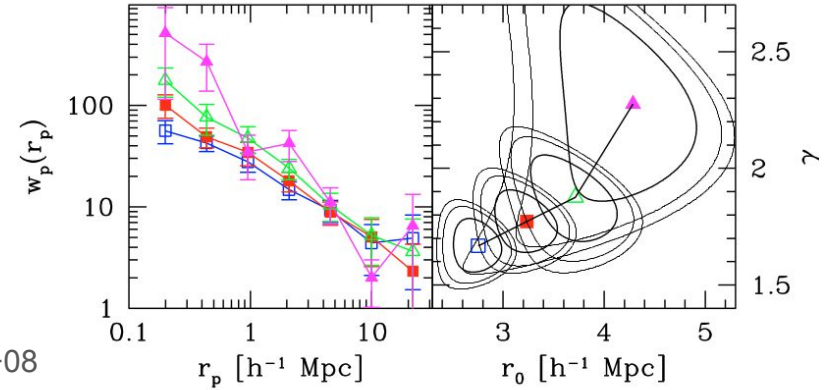
Galaxy clustering at z<2

Le Fevre+05
Pollo+05,06
Meneux+06,08
de la Torre+07,11
…

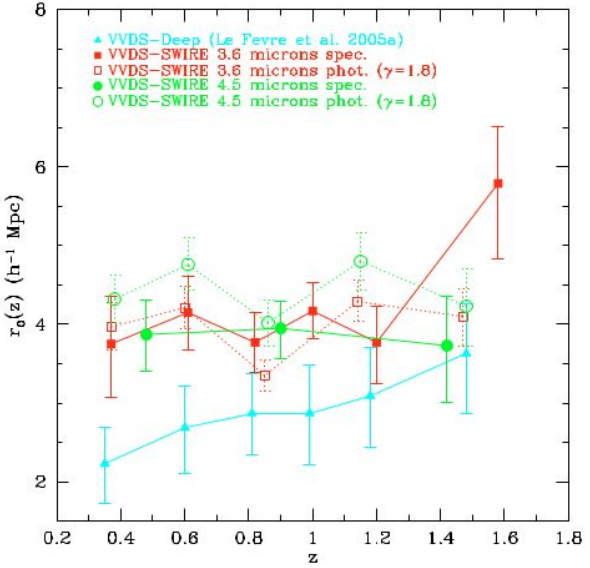


Red, early-to-intermediate type, more massive galaxies are more strongly clustered than blue, late-type, less massive galaxies
→ indication of how well they trace (are correlated with) DM density peaks

Meneux+06



Meneux+08

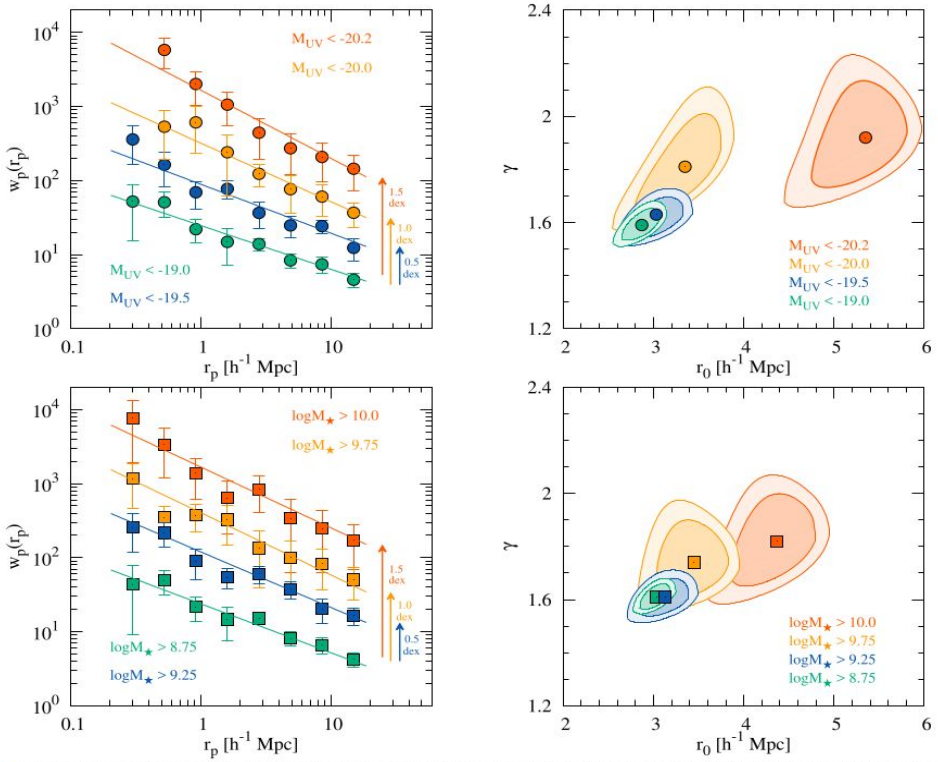


de la Torre +07

Galaxy clustering at z>2

VUDS | VIMOS Ultra Deep Survey

Durkalec+15b,18
…



Most luminous and massive galaxies are more clustered also at z>2
→ as expected from the hierarchical scenario, bigger galaxies trace better the growing structures

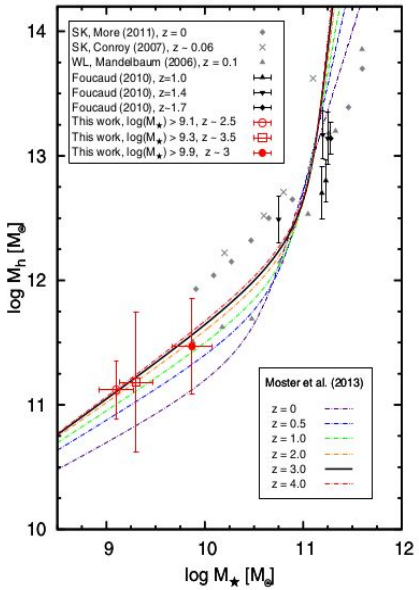
Durkalec+18

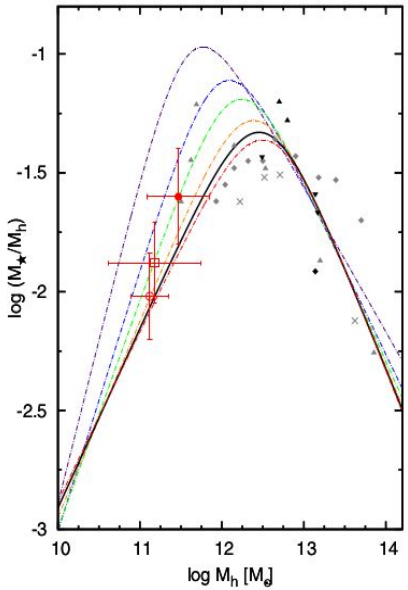
See also Ania's talk

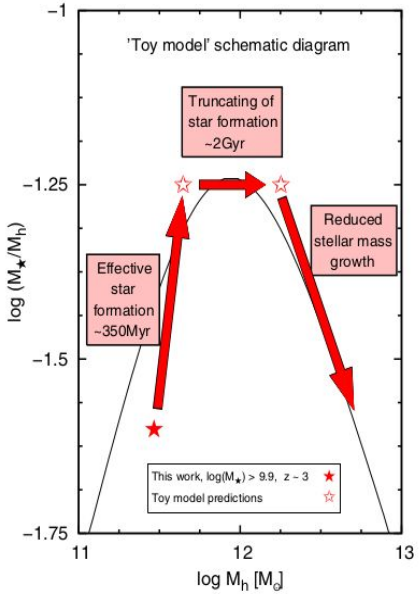
Halo occupation and stellar mass to halo mass relation

VUDS | VIMOS Ultra Deep Survey

Abbas+10
Durkalec+15,18
…







Correlation function interpreted in terms of a halo occupation model

Relation of stellar mass to halo mass

→ information of the efficiency in forming new stars and thus in assembling stellar mass in galaxies

Durkalec+15a

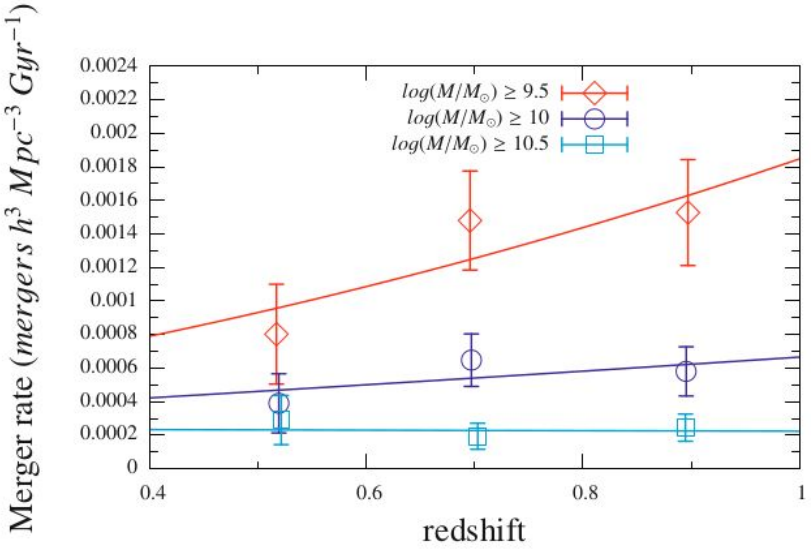
See also Ania's talk

Mergers at intermediate z

De Ravel+09
López-Sanjuan+11,12,13
…

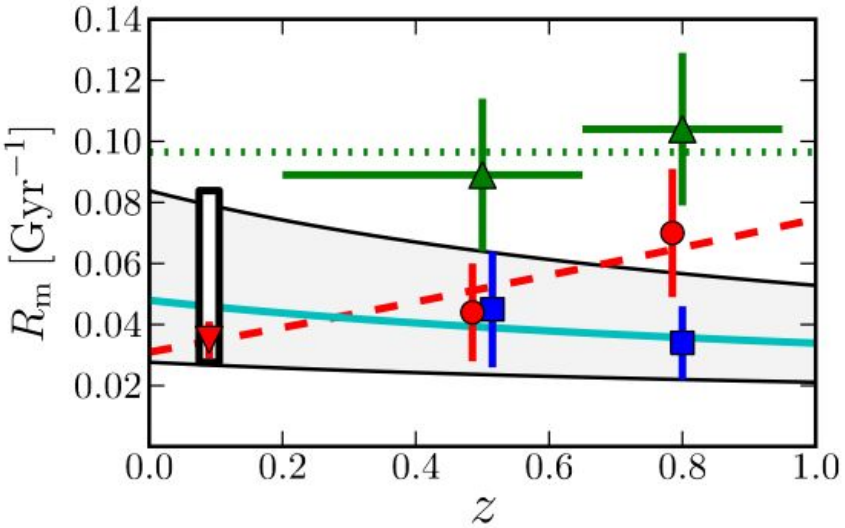
Evolution of merger rate → how efficiently stellar mass is accreted through mergers…

... for galaxies of different stellar masses



De Ravel+09

… for minor and major mergers



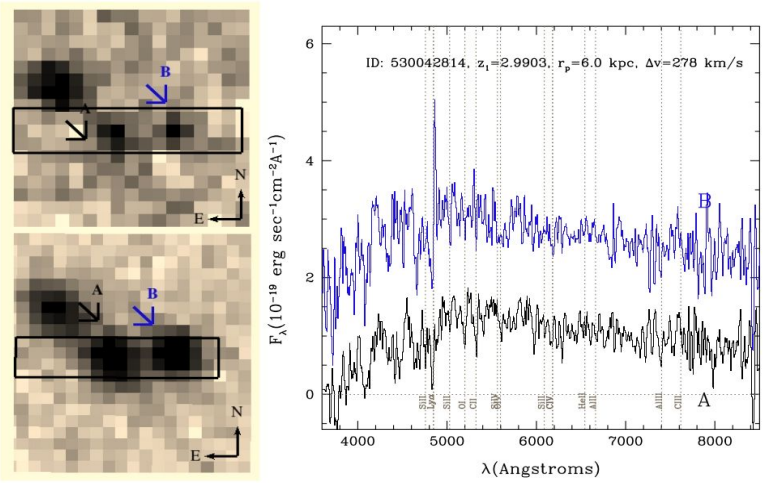
Lopez-Sanjuan+11 → See also Carlos's talk

Mergers at z>2

Tasca+14
Ribeiro+17

Estimate of merger rate at z>2 in VUDS via:

- fraction of galaxy pairs
- counts and properties of stellar clumps in HST-ACS images



Tasca+14

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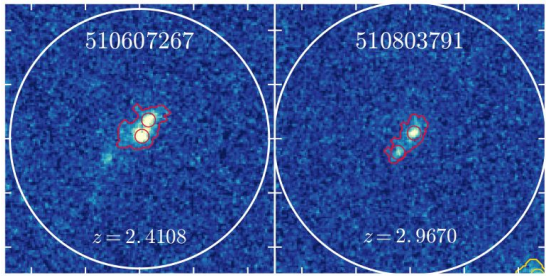
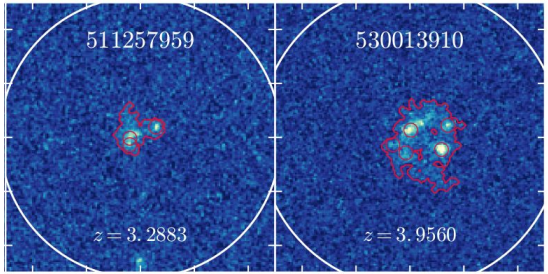


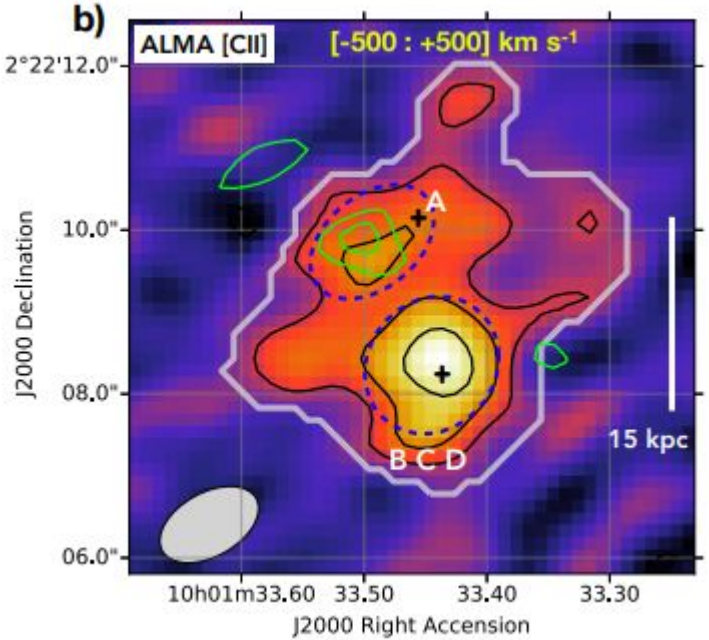
Galaxies with 2 bright clumps: clumps have properties similar to those of merging pairs



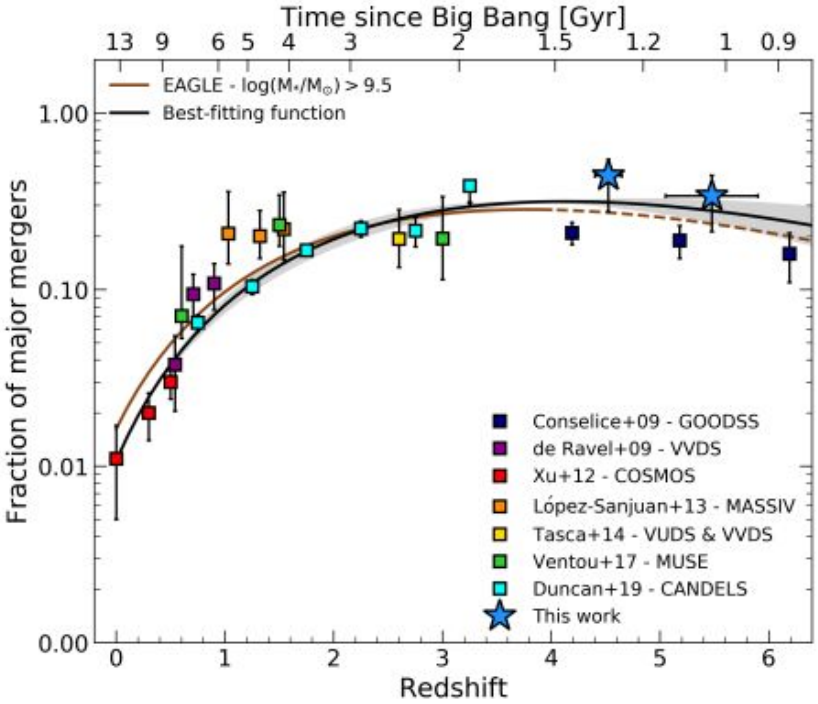
Galaxies with >2 faint clumps: violent disk instabilities or minor merger events

Mergers at even higher z

Ginolfi+20
Romano+21



Ginolfi+2020: A three way merger in the core of a massive proto-cluster at z~4.6 (see also Jones+2020, 2021)



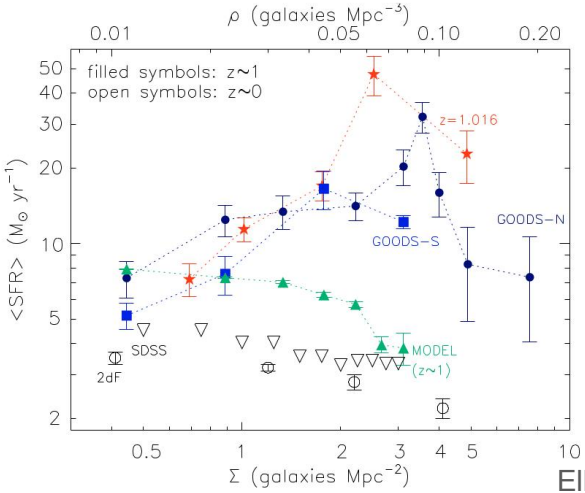
Romano+21: major merger rate of galaxies at z~5 from ALPINE

Galaxy properties as a function of environment →**early 2000s**, z~1

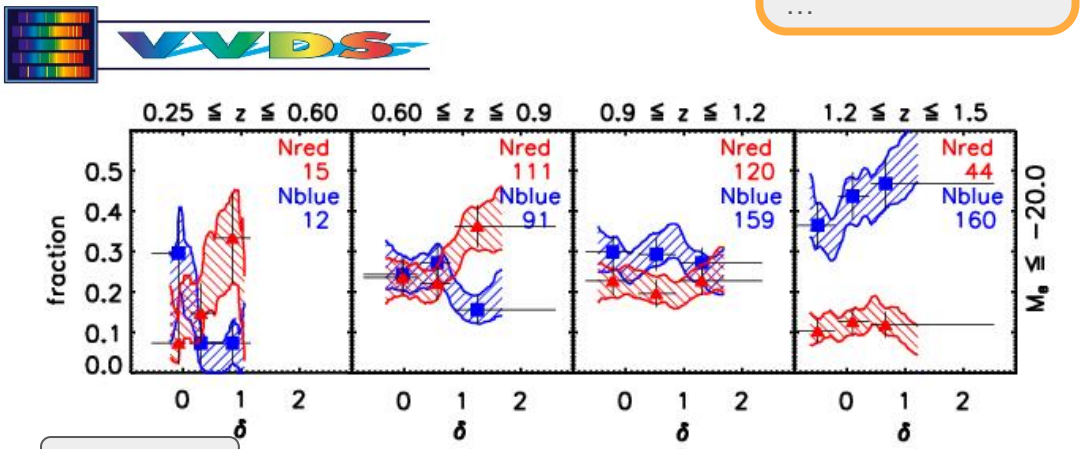
Cucciati+06,10
Scodeggio+09
Lopez-SanJuan+13
…

Hot topic: find the epoch of the inversion of the local universe trends
(e.g., SFR-density, color-density)

Competitions with other teams, especially with the DEEP2 team

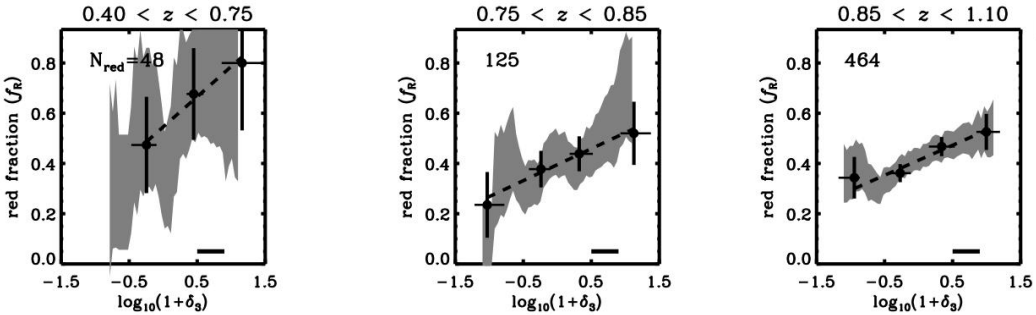


Elbaz+07



DEEP2

Cucciati+06



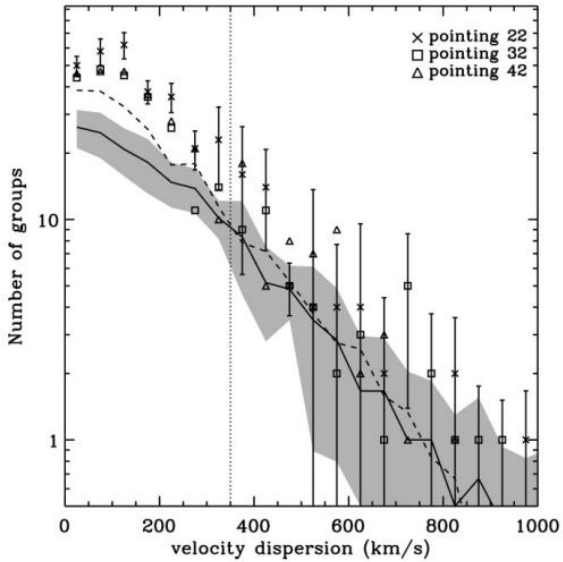
Cooper+07

Galaxy properties as a function of environment →**early 2000s**, z~1

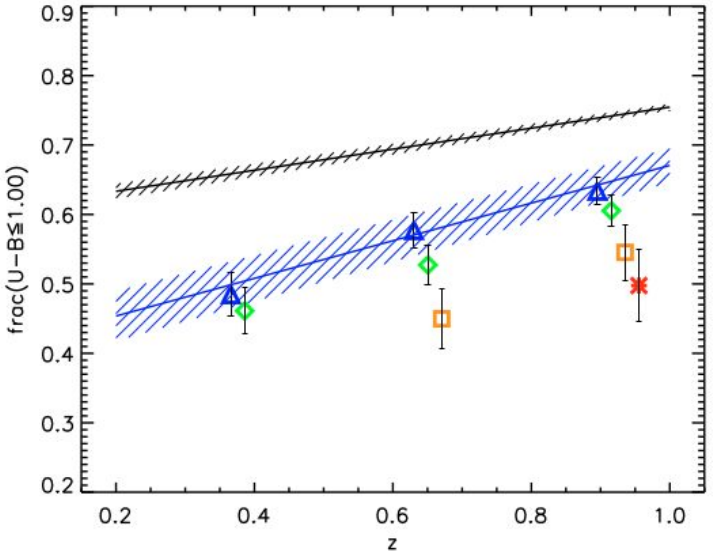
Cucciati+06,10
Lopez-SanJuan+13
…

… also for what concerns the identification of galaxy groups!

DEEP2 Gerke+04



VVDS Cucciati+10



Fraction of blue galaxies in groups, as a function of redshift and group richness

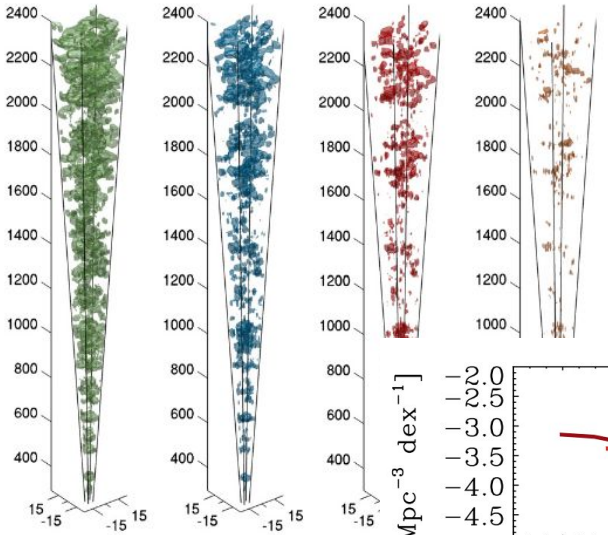
Olivier's creativity and drive was fueled by this competition, and the results were in turn aided by this creativity and drive.

Galaxy properties as a function of environment
→**late 2000s, early 2010s**, z~1

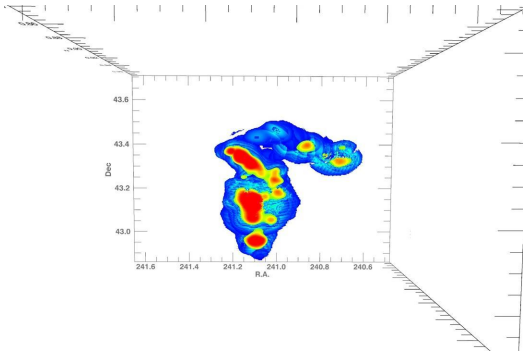
The zCOSMOS and VIPERS surveys were made possible also thanks to the experience gained through working on VVDS

With these data sets we increased our understanding of environmental effect on different scales and the distinct role of stellar mass and environment in galaxy evolution, also for rare galaxy populations.

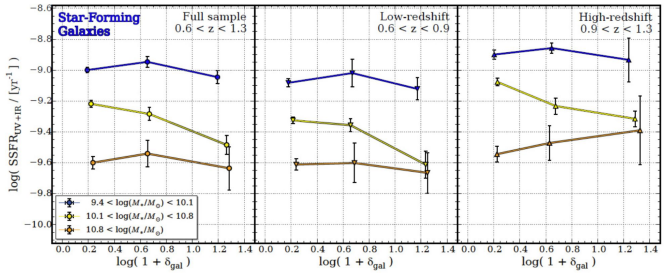
We also sharpened our tools for future surveys



Galaxy properties as a function of environment →**mid-2010s**, a rebirth of z~1 studies and a look towards higher redshift

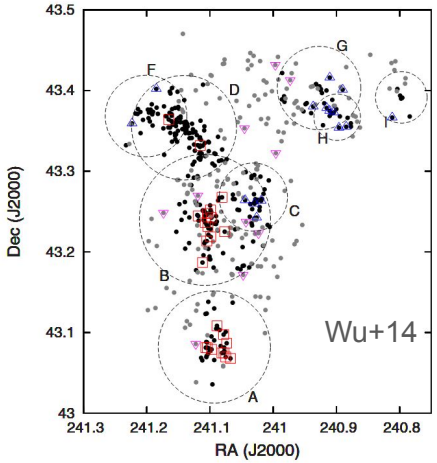


Tomczak+19

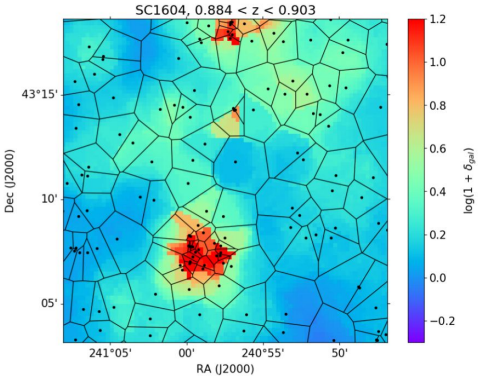


SFR-density and color-density trends shown to persist to z~1.5, need to go to higher redshift!

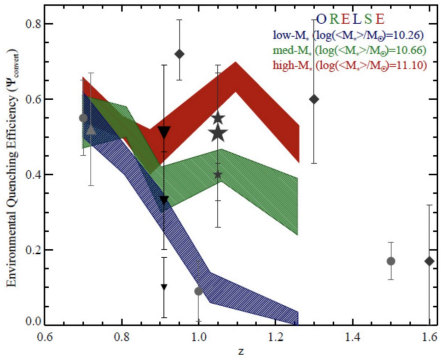
Supercluster SC1604 at z~0.9



Voronoi-MC method applied to groups and clusters at z~0.9



Hung+19

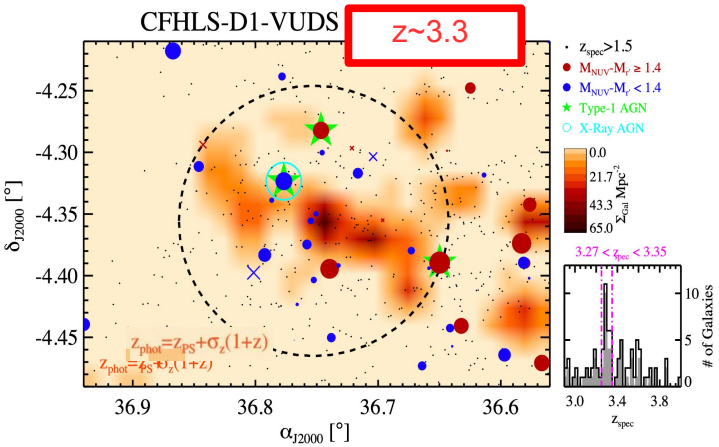


Lemaux+19

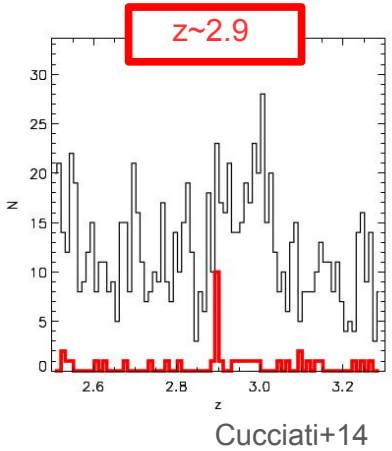
Galaxy properties as a function of environment →**mid-to-late 2010s**, the realm of protoclusters

Cucciati+14,18
Lemaux+14,18,22

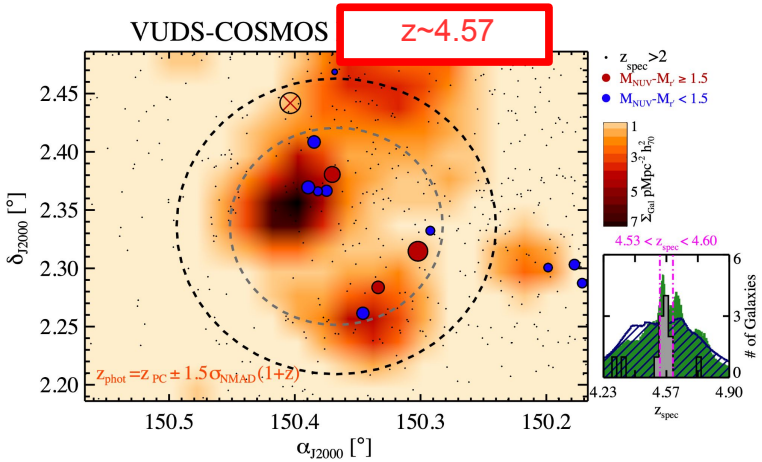
From serendipitous discoveries…



Lemaux+14



Cucciati+14

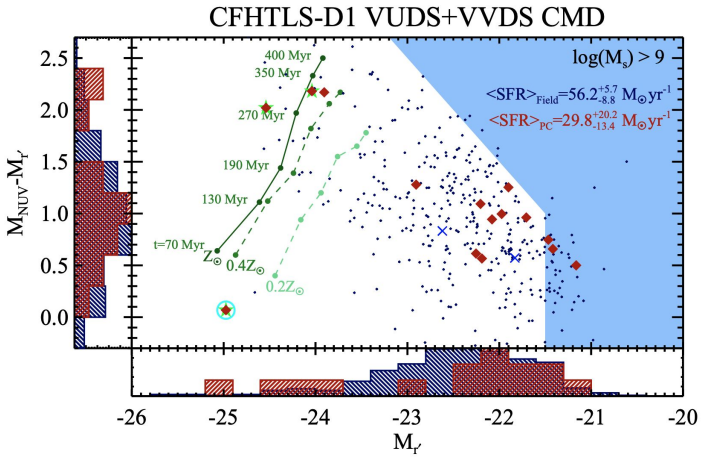


Lemaux+18

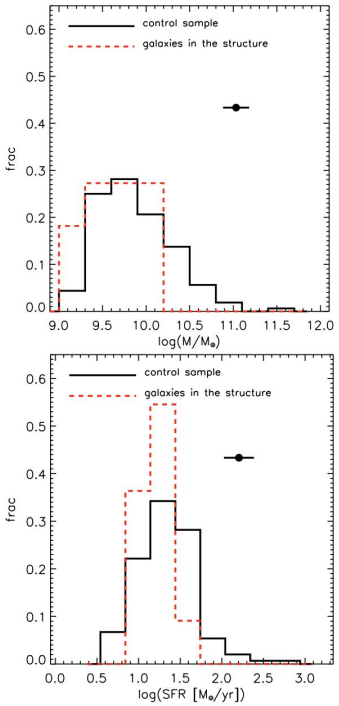
Galaxy properties as a function of environment →**mid-to-late 2010s**, the realm of protoclusters

Cucciati+14,18
Lemaux+14,18,22

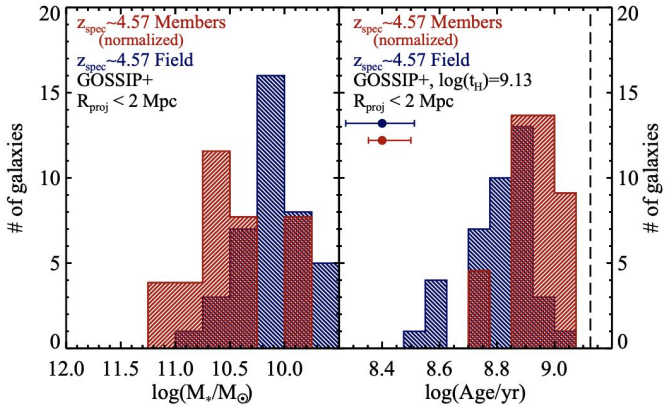
…and rudimentary initial explorations showing the **immense heterogeneity of protocluster populations…**



Lemaux+14



Cucciati+14



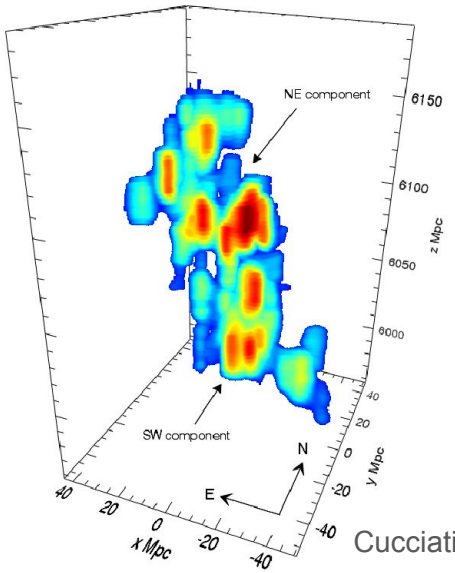
Lemaux+18

Galaxy properties as a function of environment →**mid-to-late 2010s**, the realm of protoclusters

Cucciati+14,18
Lemaux+14,18,22

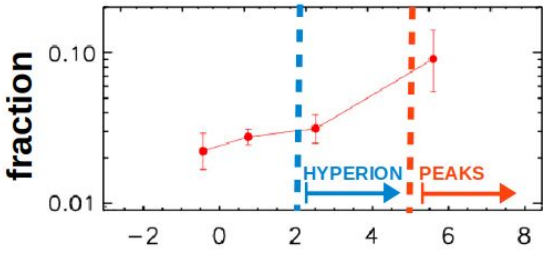
… to the discovery and careful characterization of large scale structure..

The Hyperion proto-supercluster

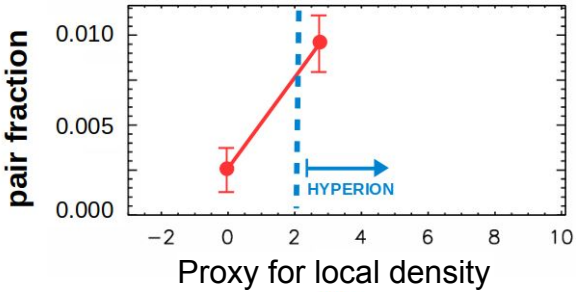


Cucciati+18

In-situ mass growth:
fraction of galaxies experiencing nuclear (X-ray detected) or starburst (FIR-detected) activities



Ex-situ mass growth:
higher pair fraction in higher densities

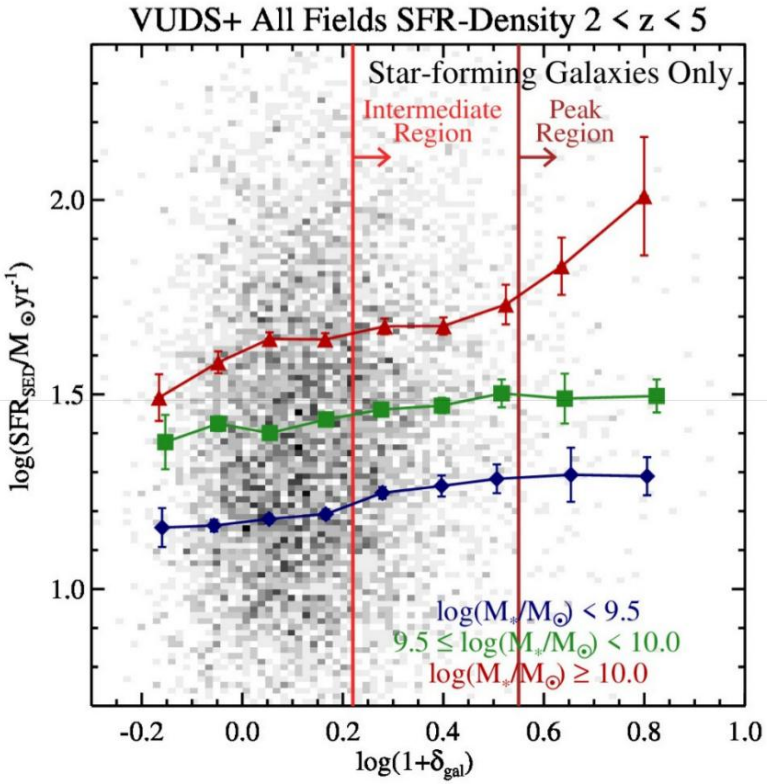


The discovery of proto-clusters, especially Hyperion, was an unexpected joy from the VUDS survey. Olivier was deeply involved in its discovery and its promotion as a structure worthy of serious attention and future study.

Galaxy properties as a function of environment →**mid-to-late 2010s**, the realm of protoclusters

Cucciati+14,18
Lemaux+14,18,22

… to a systematic environment parameterization to allow for a statistically robust detection of **the inversion of the SFR-density relation**

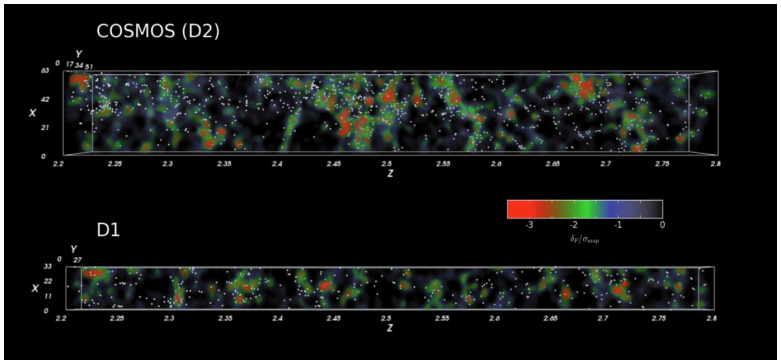


Lemaux+22

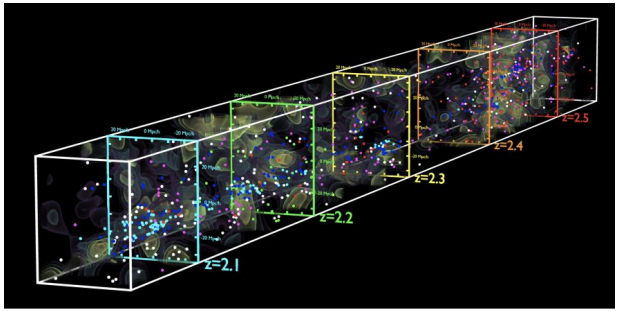
This result was the culmination of over two decades of interest, exploration, and intense study on the topic, starting with the earliest works with VVDS; a milestone achievement for Olivier.

VUDS Legacy (1): external collaborations

Lya tomography maps



Newman+20 (LATIS)

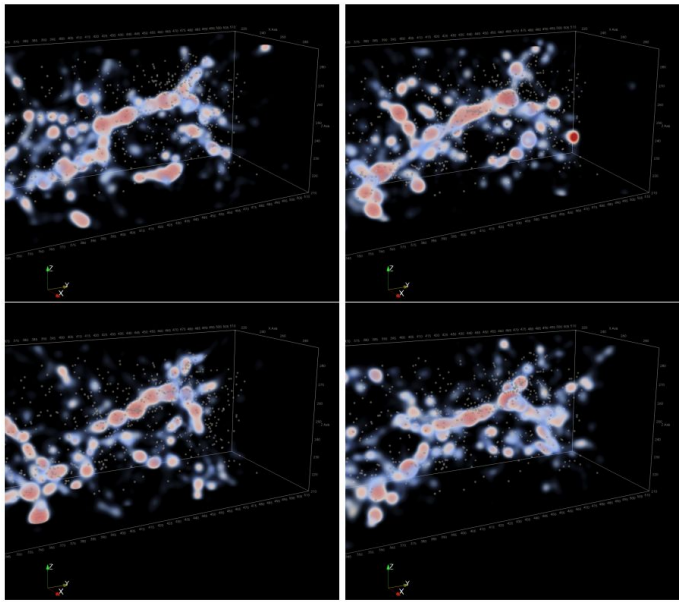


Horowitz+21(CLAMATO)

Future fate of galaxy protoclusters (and Hyperion!)

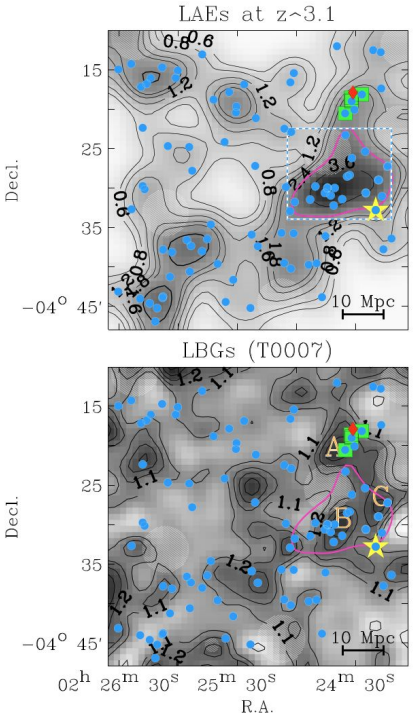
(Ata+22)

See e.g. Metin's talk

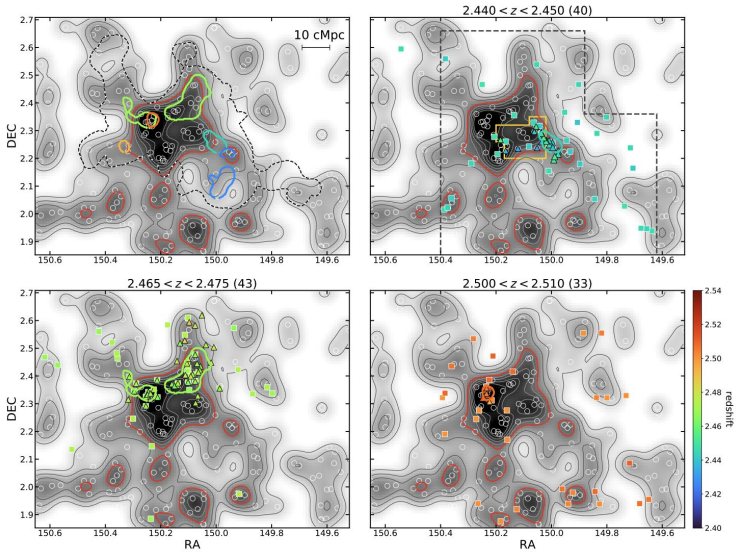


VUDS Legacy (1): external collaborations

Lya imaging of CFHTLS-D1 (Shi+19)



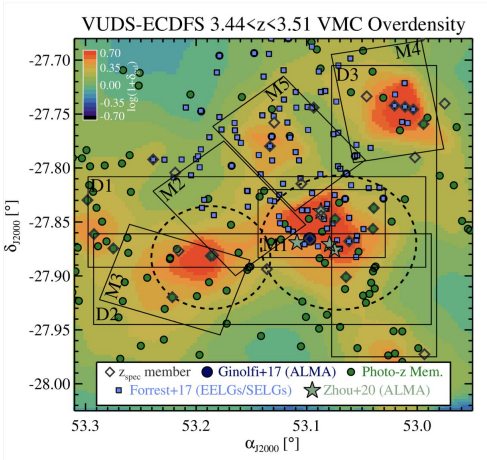
Lya imaging of Hyperion (Huang+22)

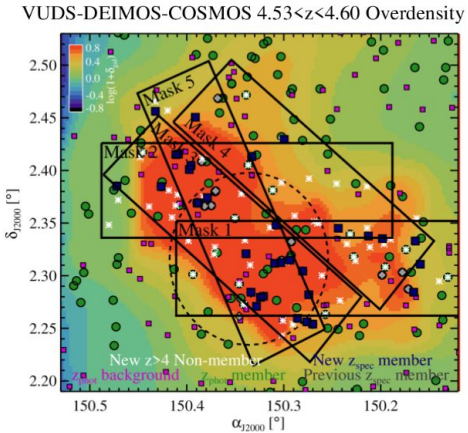


See also several other works that used VUDS data (eg Smolčić+17, Newman+22..)

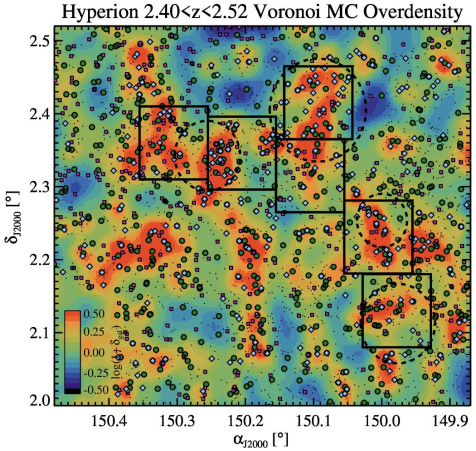
Olivier's willingness to share data obtained through many years of hard work, and his encouragement to engage in discussions across collaborations and viewpoints, dramatically enhanced these studies

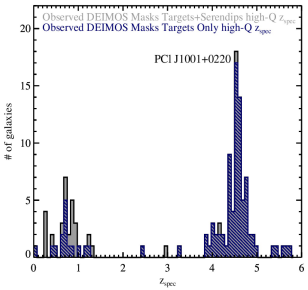
VUDS Legacy (2): the C3VO survey

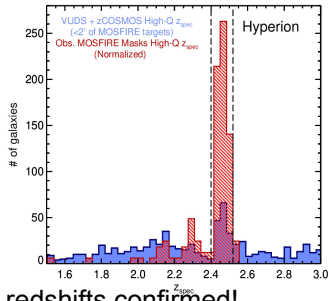




~35 night followup of six proto-structures with Keck DEIMOS/MOSFIRE and Subaru MOIRCS/SWIMS



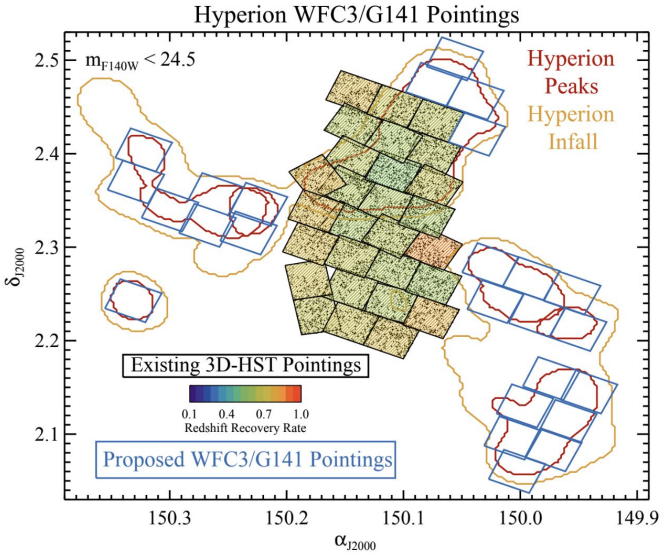




100s of new member redshifts confirmed!

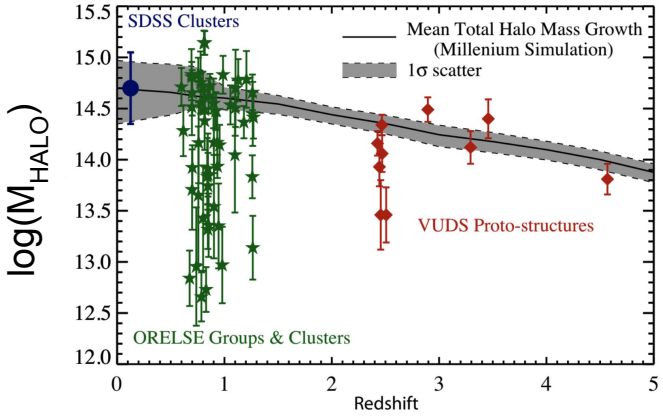
Charting Cluster Construction with VUDS and ORELSE

50 orbit HST/WFC3 G141 grism program awarded in 2021 to observe *all* of the intermediate- to high-density regions of Hyperion



VUDS Legacy (2): the C3VO survey

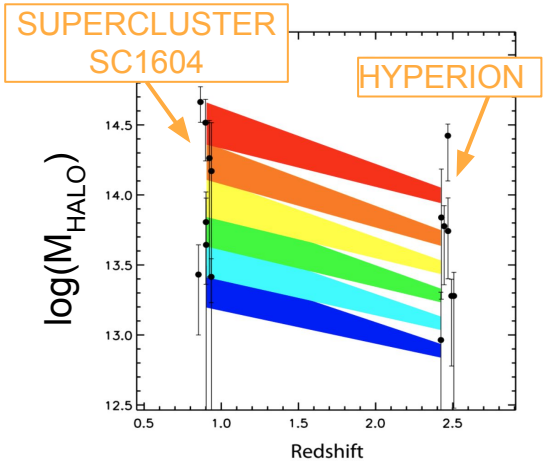
Charting Cluster Construction with VUDS and ORELSE

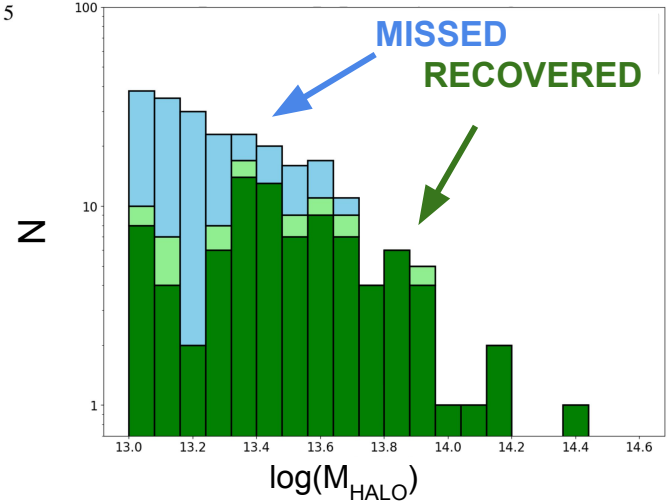


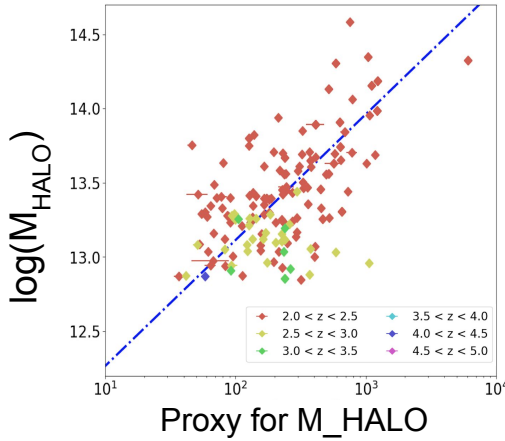
Ongoing: **systematic identification of protoclusters in VUDS,** using VUDS-like mocks to assess:

- the completeness of the protocluster catalogue
- how well we recover the total halo mass

→ excellent preliminary results



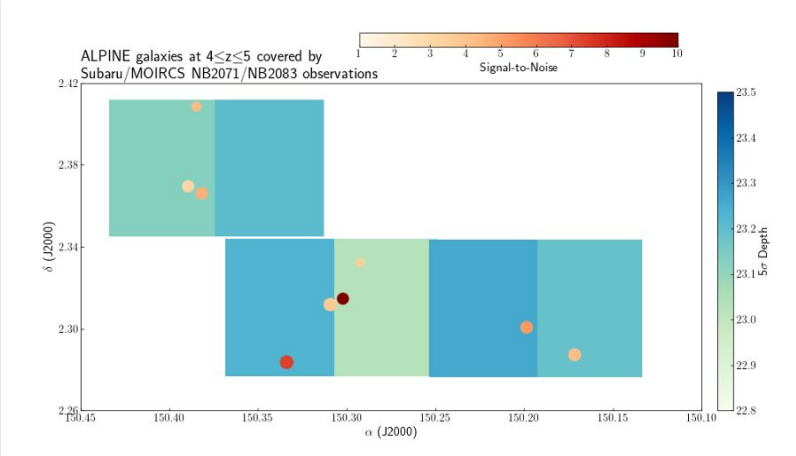




Hung+ in prep

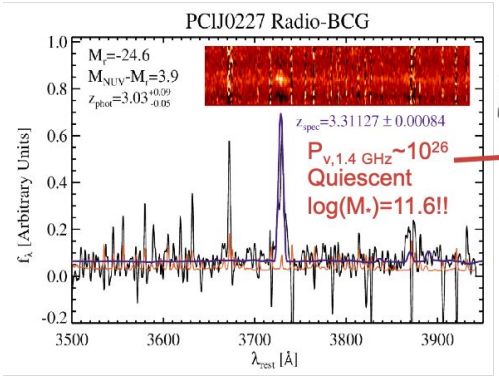
VUDS Legacy (2): the C3VO survey

Charting Cluster Construction with VUDS and ORELSE

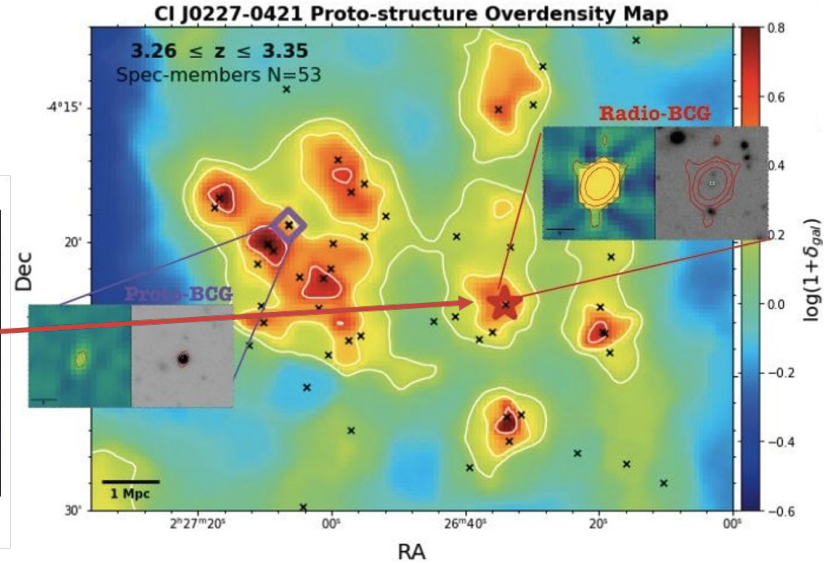


MOIRCS NB imaging of PCI1001+0220 at z~4.57 targeting [OII]

(synergy with ALPINE! see Vanderhoof+21)



Shen+21 (see also Forrest+20b)



Dr. Olivier Le Fèvre
November 1960 – June 2020

A joint statement from his former ERC team in Marseille and other members of the VUDS family:

…Olivier's vision not only in the science that he pursued, but the manner in which he pursued it, and the courage and boldness to consider bringing into his team those steeped in cultures from every part of the world, profoundly impacted our lives. It is due to his actions, his leadership, and his vision that many of us find ourselves with the opportunities that we have before us today. Whether we continue to explore deeper into the universe or have since left astronomy for more terrestrial concerns, his impact is felt deeply and will remain an indelible legacy in our lives…

Olivier at a BBQ with his ERC team at his home in Le Castellet, France in 2014

Olivier at a collaboration meeting dinner near Davis, California in 2018