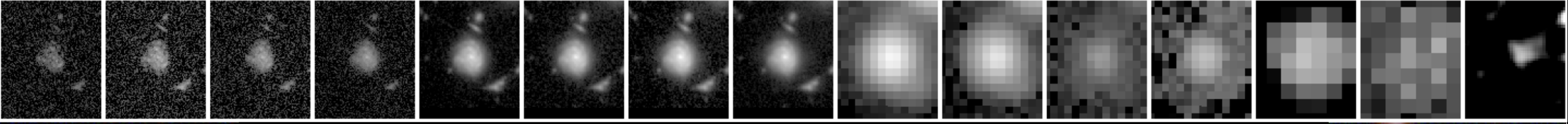
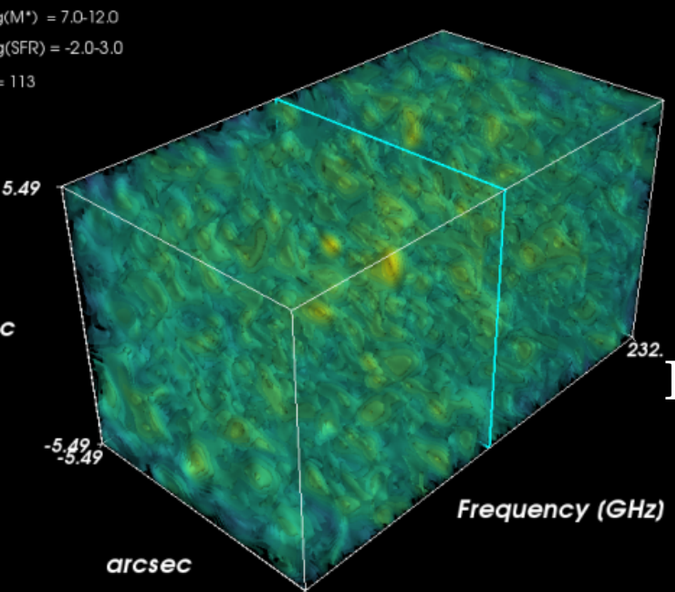
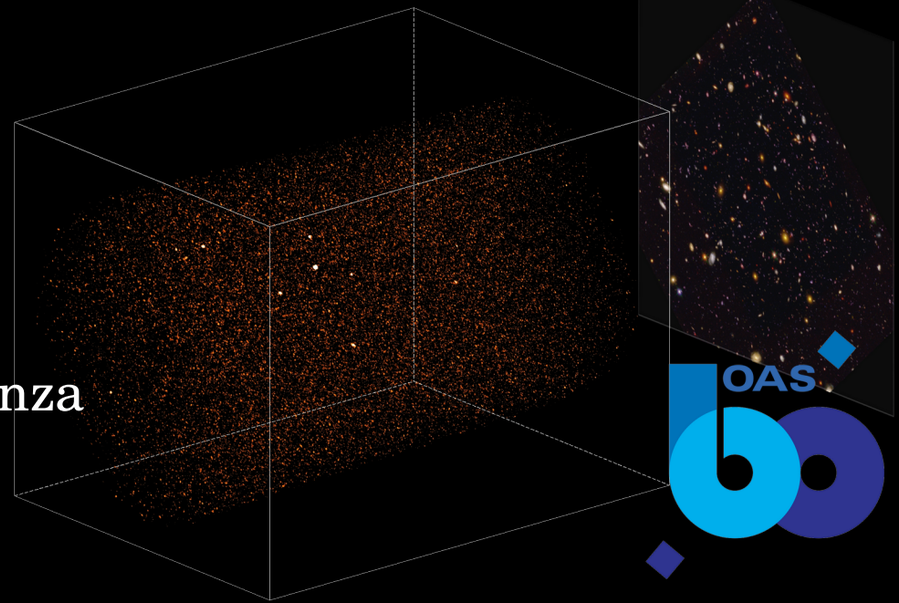


The ultimate census of molecular gas in distant galaxies

Roberto Decarli

INAF – Osservatorio di Astrofisica e Scienza dello Spazio di Bologna





- first extragalactic ALMA LP
- target: Hubble Ultra-Deep Field
- total of 200 hours, bands 3 & 6
- executed 2017-2019
- builds on ASPECS pilot program (2015/2016)

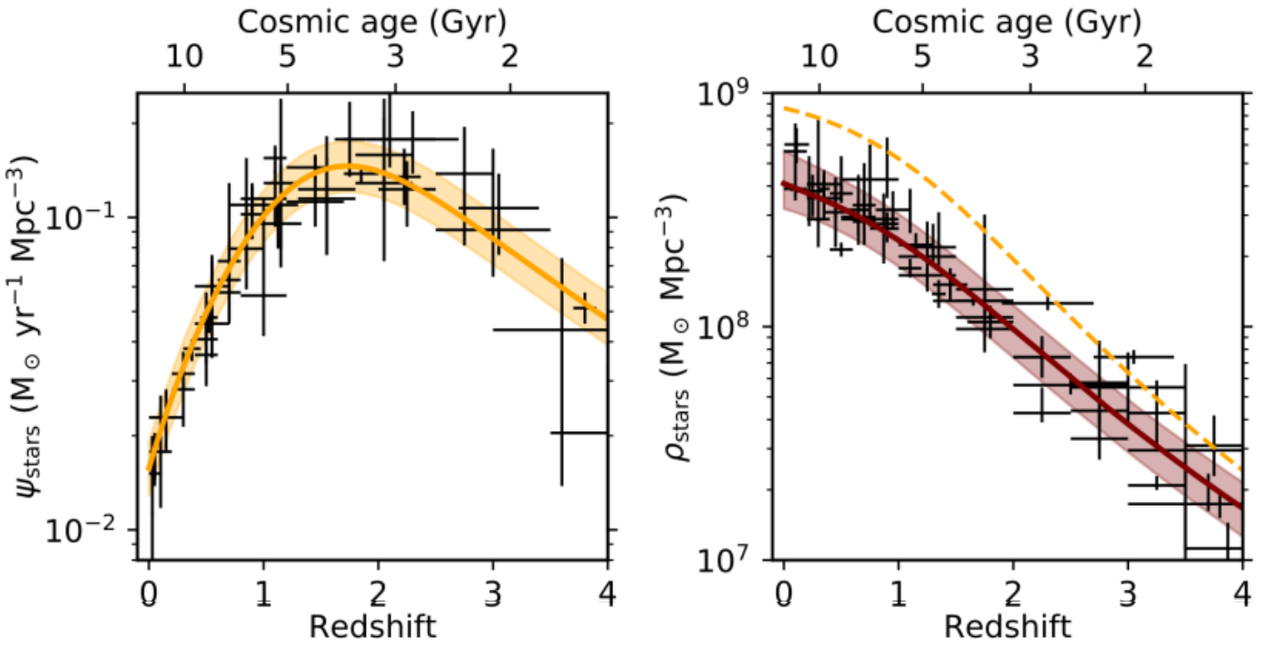
ASPECS

Manuel Aravena *(Universitad Diego Portales, Chile)*
Chris Carilli *(National Radio Astronomy Observatory, USA)*
Roberto Decarli *(Observatory of Astrophysics and Space Science of Bologna, Italy)*
Fabian Walter *(Max Planck Institute for Astronomy, Germany)*

Roberto Assef *(Universidad Diego Portales, Chile)*
Roland Bacon *(University of Lyon, France)*
Franz Bauer *(Pontificia Universidad Católica, Chile)*
Frank Bertoldi *(Argelander Institute for Astronomy, Germany)*
Leindert Boogaard *(Leiden Observatory, Netherlands)*
Rychard Bouwens *(Leiden Observatory, Netherlands)*
Thierry Contini *(Institut de Recherche en Astrophysique et Planétologie, Toulouse, France)*
Paulo C. Cortes *(Joint ALMA Observatory)*
Pierre Cox *(Intistut d'Astrophysique de Paris, France)*
Elisabete da Cunha *(University of Western Australia, Australia)*
Emanuele Daddi *(Laboratoire AIM, CEA/DSM-CNRS-Université Paris Diderot, France)*
Tanio Diaz-Santos *(Universidad Diego Portales, Chile)*
David Elbaz *(Laboratoire AIM, CEA/DSM-CNRS-Université Paris Diderot, France)*
Jorge Gonzalez-Lopez *(Las Campanas Observatory/Universidad Diego Portales)*
Jacqueline Hodge *(Leiden Observatory, Netherlands)*
Hanae Inami *(University of Hiroshima, Japan)*
Rob J. Ivison *(Euroean Southern Observatory)*
Melanie Kaasinen *(Max Planck Institute for Astronomy, Germany)*
Olivier Le Fevre *(Laboratoire d'Astrophysique de Marseille, France)*
Benjamin Magnelli *(Argelander Institute for Astronomy, Germany)*
Marcel Neeleman *(Max Planck Institute for Astronomy, Germany)*
Mladen Novak *(Max Planck Institute for Astronomy, Germany)*
Pascal Oesch *(University of Geneva, Switzerland)*
Gergo Popping *(European Southern Observatory)*
Dominik Riechers *(Cornell University, USA)*
Hans-Walter Rix *(Max Planck Institute for Astronomy, Germany)*
Mark Sargent *(Sussex University, United Kingdom)*
Ian Smail *(Durham University, United Kingdom)*
Rachel Somerville *(Flatiron Institute, USA)*
Mark Swinbank *(Durham University, United Kingdom)*
Bade Uzgil *(California Institute of Technology, USA)*
Paul van der Werf *(Leiden Observatory, Netherlands)*
Jeff Wagg *(Square Kilometer Array Observatory)*
Axel Weiss *(Max Planck Institute for Radioastronomy, Germany)*
Lutz Wisotzky *(Leibniz Institute for Astrophysics, Germany)*

www.aspecs.info

We now know the Cosmic Star Formation History

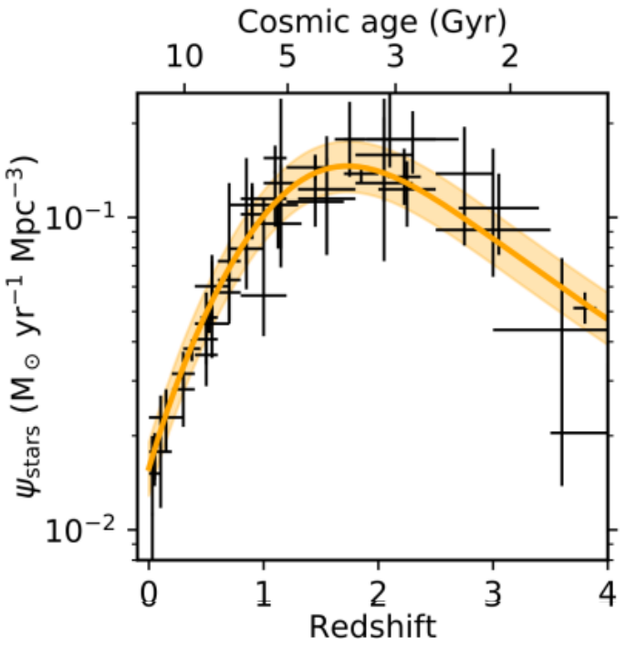


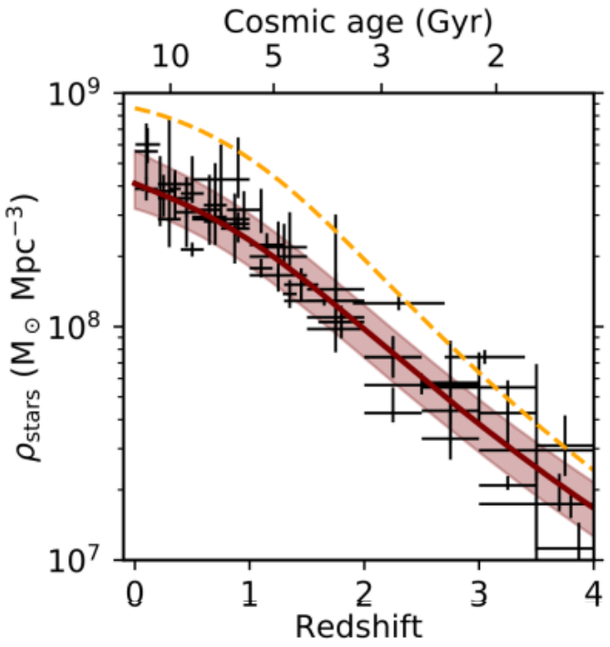
star formation rate density

stellar mass density

Madau & Dickinson (2014)

What drives the Cosmic Star Formation History?





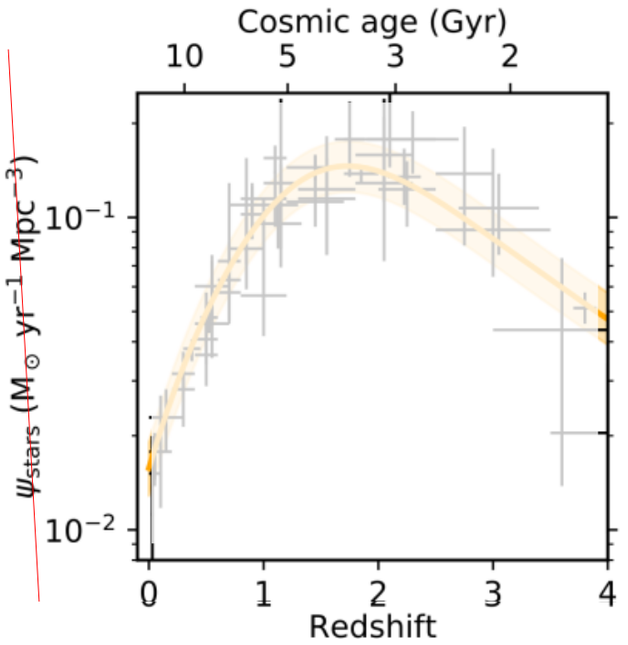
star formation rate density

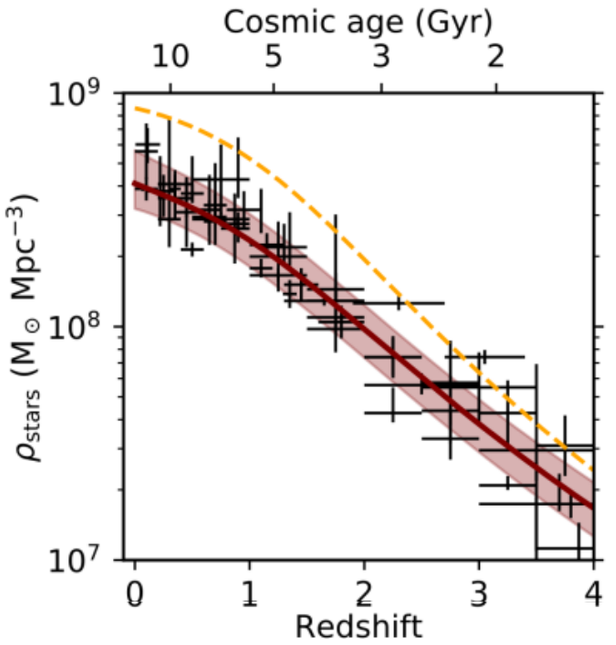
stellar mass density

Madau & Dickinson (2014)

What drives the Cosmic Star Formation History?

Gas cosmic density





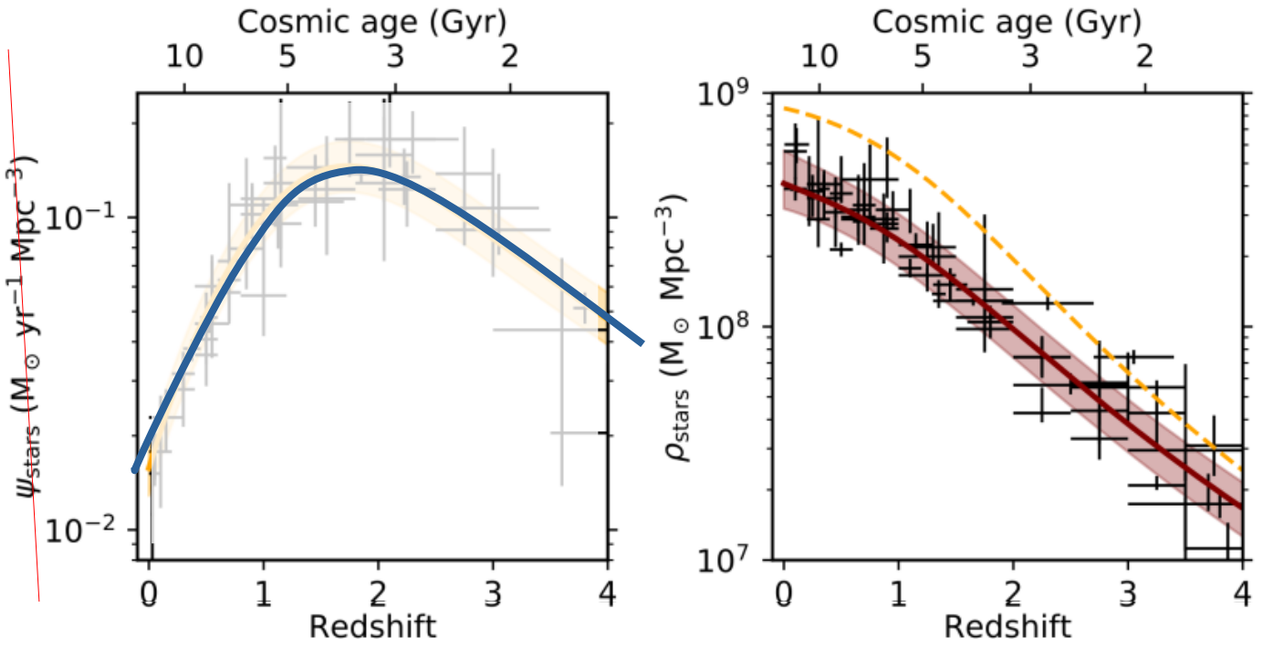
star formation rate density

stellar mass density

Madau & Dickinson (2014)

What drives the Cosmic Star Formation History?

Gas cosmic density



star formation rate density

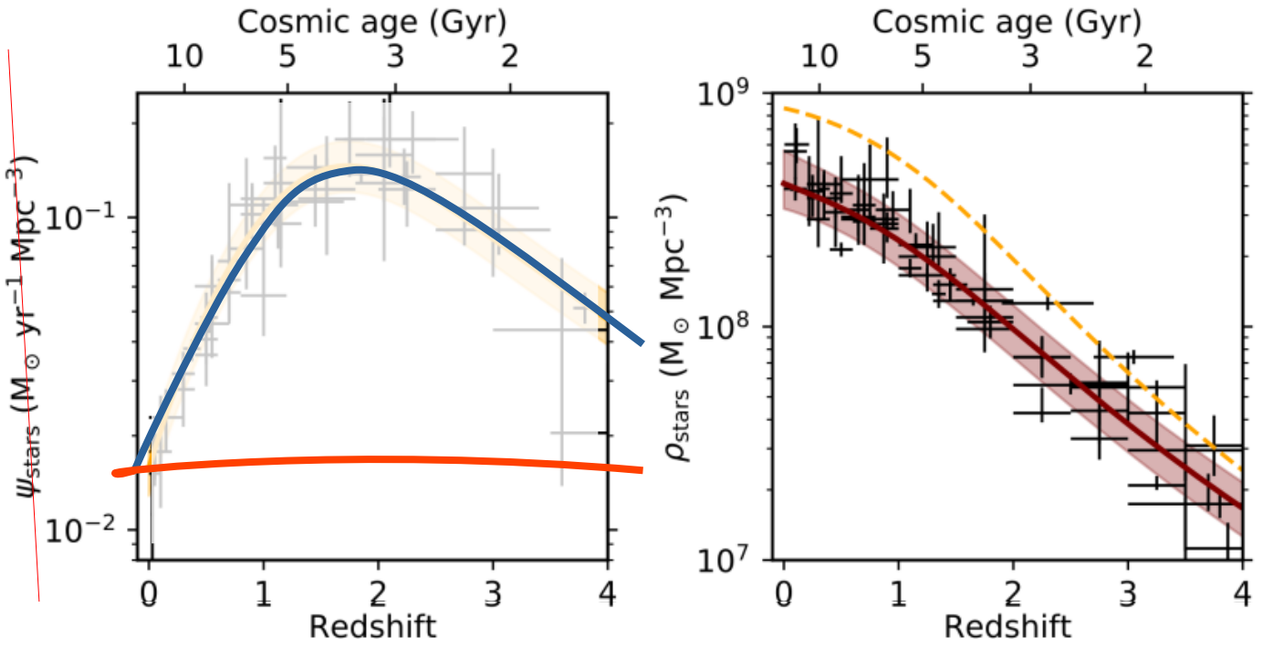
stellar mass density

Does the gas supply evolve?

Madau & Dickinson (2014)

What drives the Cosmic Star Formation History?

Gas cosmic density



star formation rate density

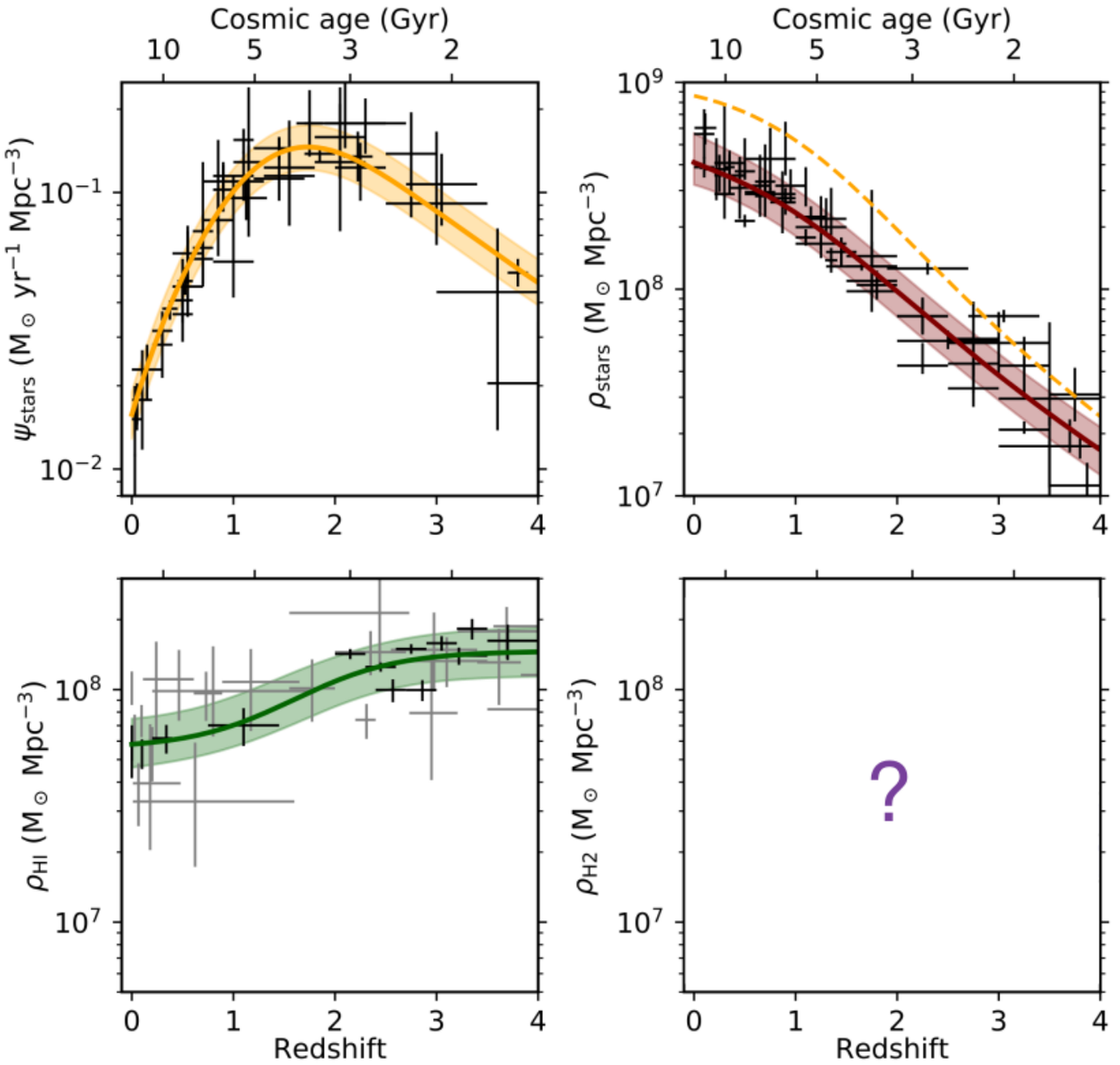
stellar mass density

Does the gas supply evolve?

Does the star formation efficiency change?

Madau & Dickinson (2014)

What drives the Cosmic Star Formation History?



star formation rate density

stellar mass density

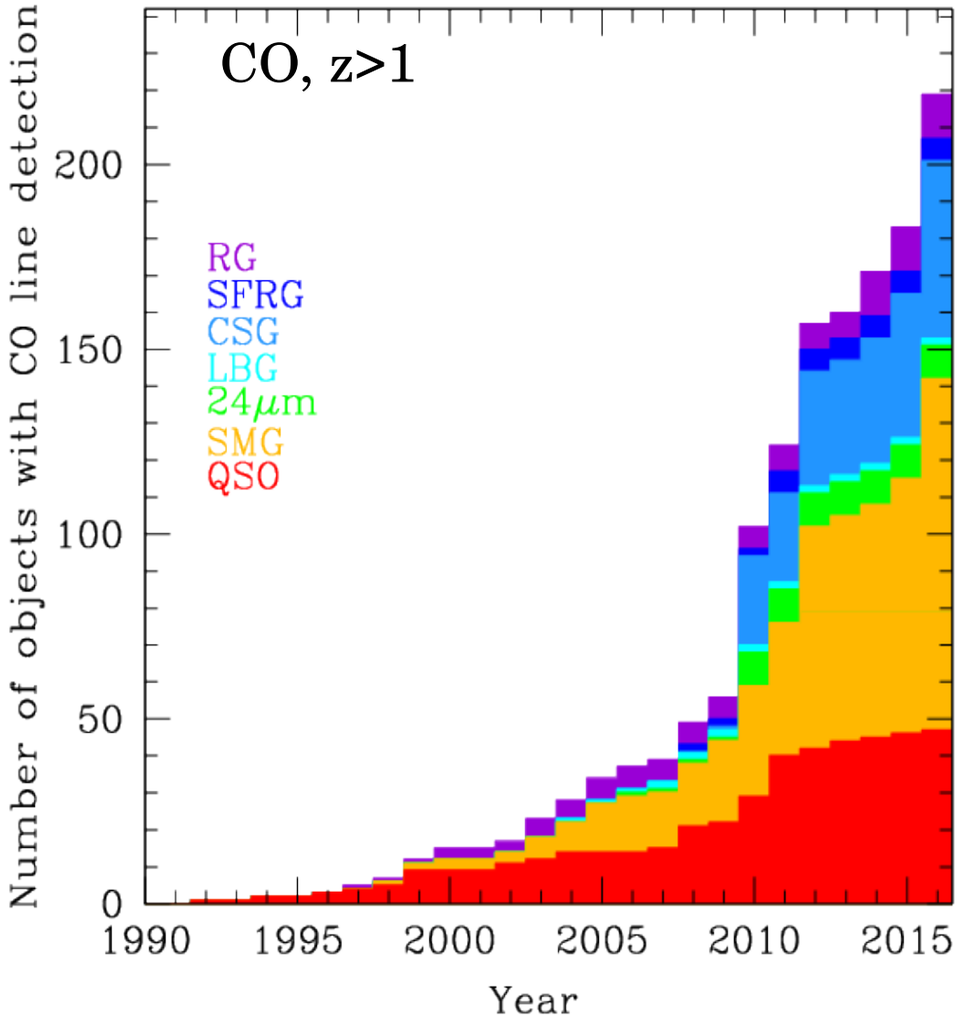
atomic hydrogen density

molecular gas density

e.g., Madau & Dickinson 2014, Neeleman et al. 2017

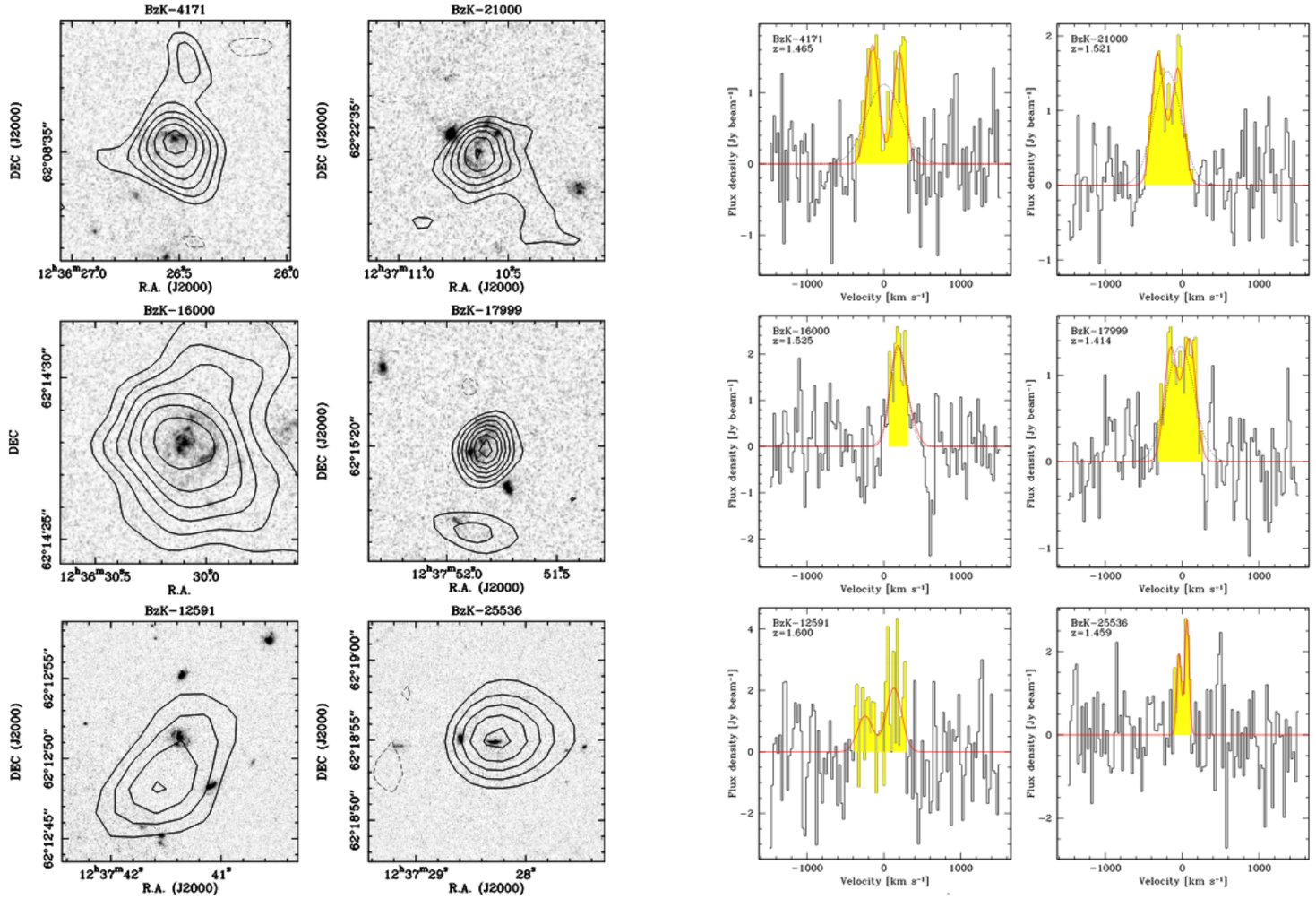
Molecular gas at high-z

Carilli & Walter (2013) + update



Until ~2010,
only SMGs+QSOs

Molecular gas at high-z (beyond SMGs)

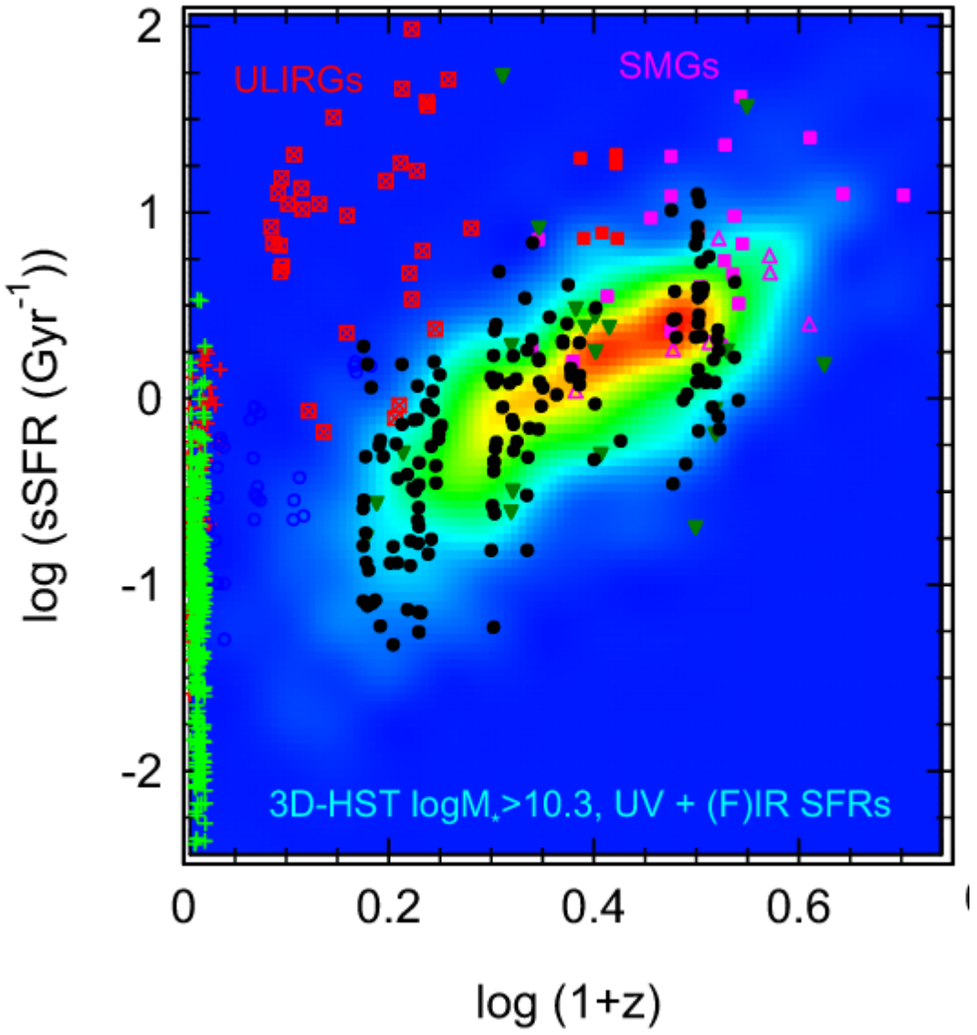


Daddi et al. (2010)

First CO detections of main sequence galaxies, z~1.5

5-20 hr on source

Molecular gas at high-z (beyond SMGs)



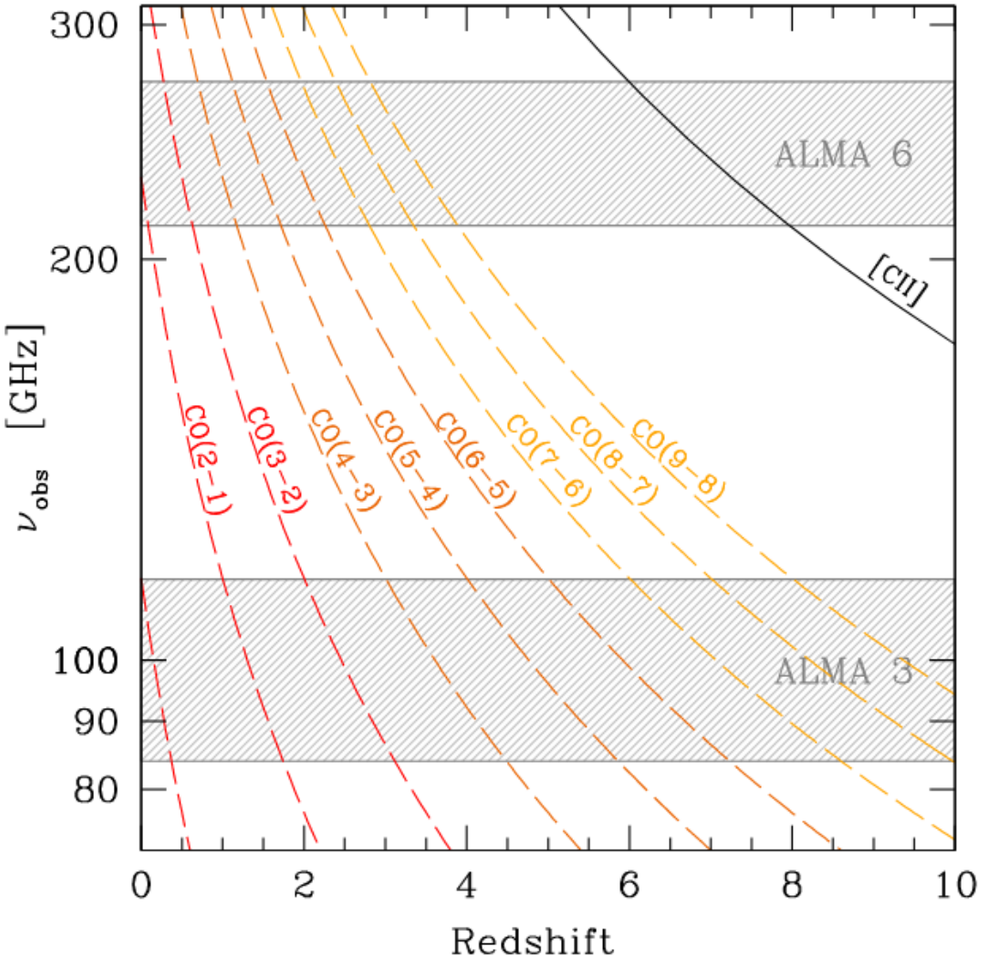
Tacconi et al. (2018)

Targeted observations

PHIBSS1:
M_{star}>2e10 M_o
SFR>30 M_o yr^{-1}

PHIBSS2:
~200 galaxies
at z>0.5

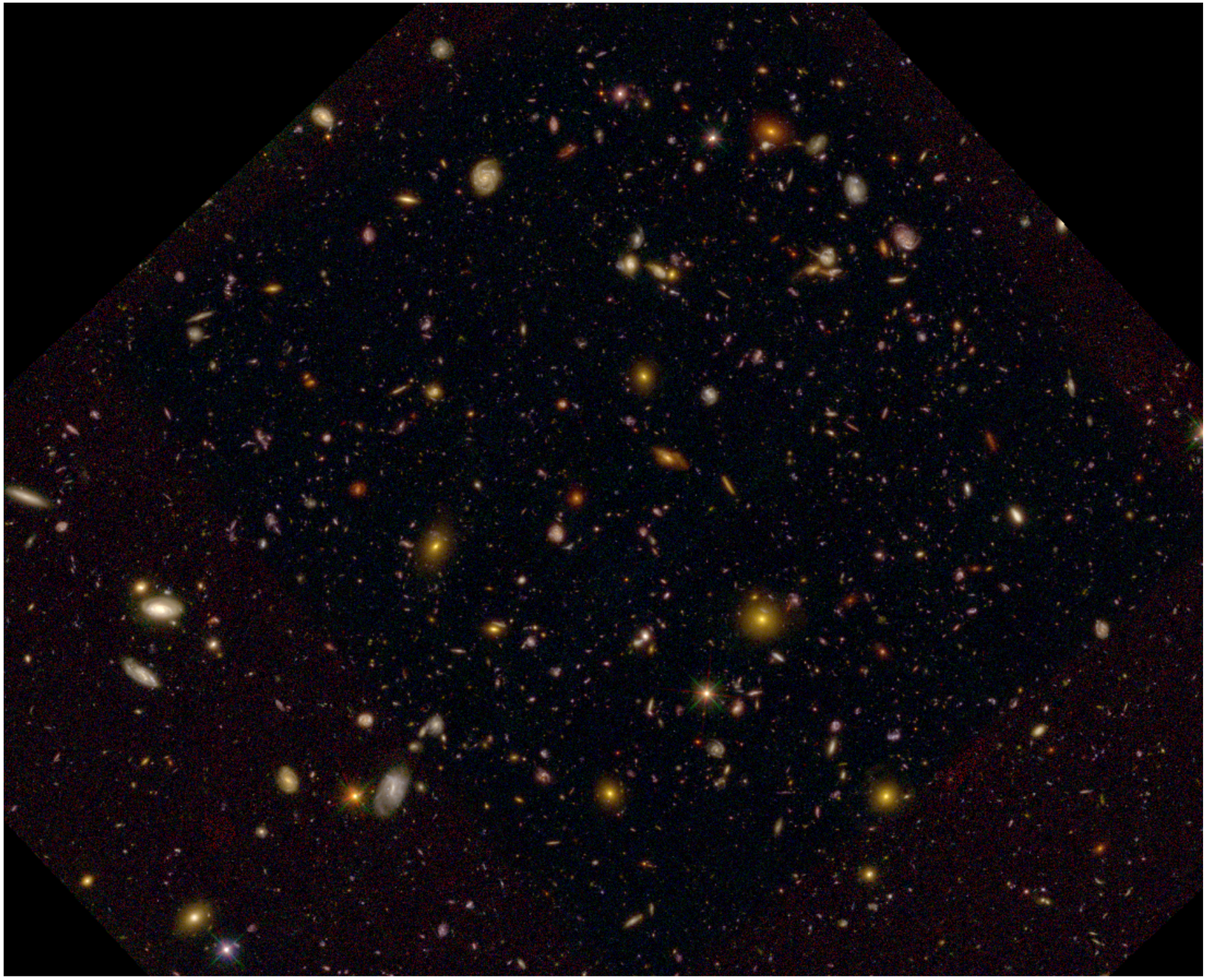
What is ASPECS?

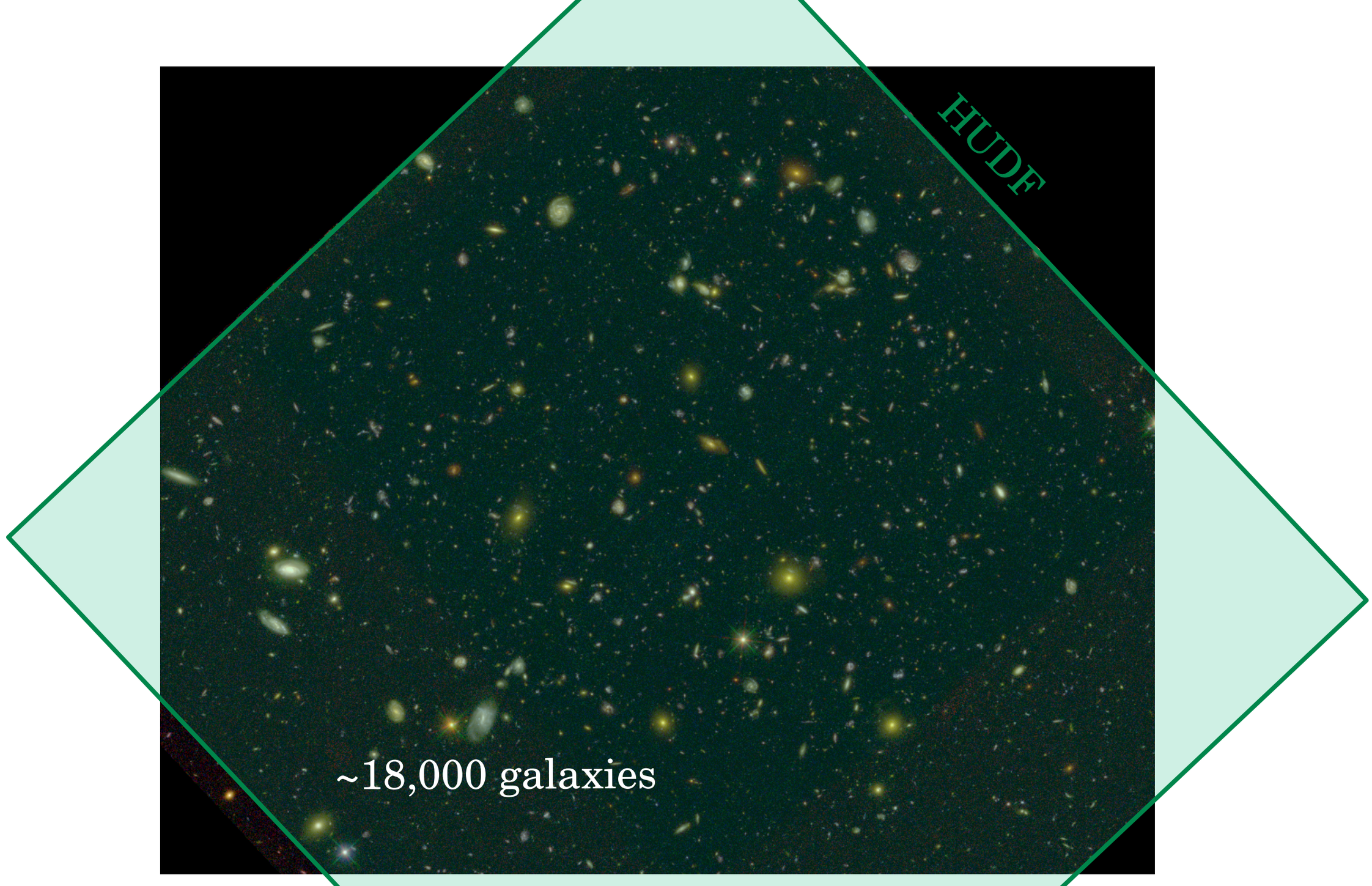


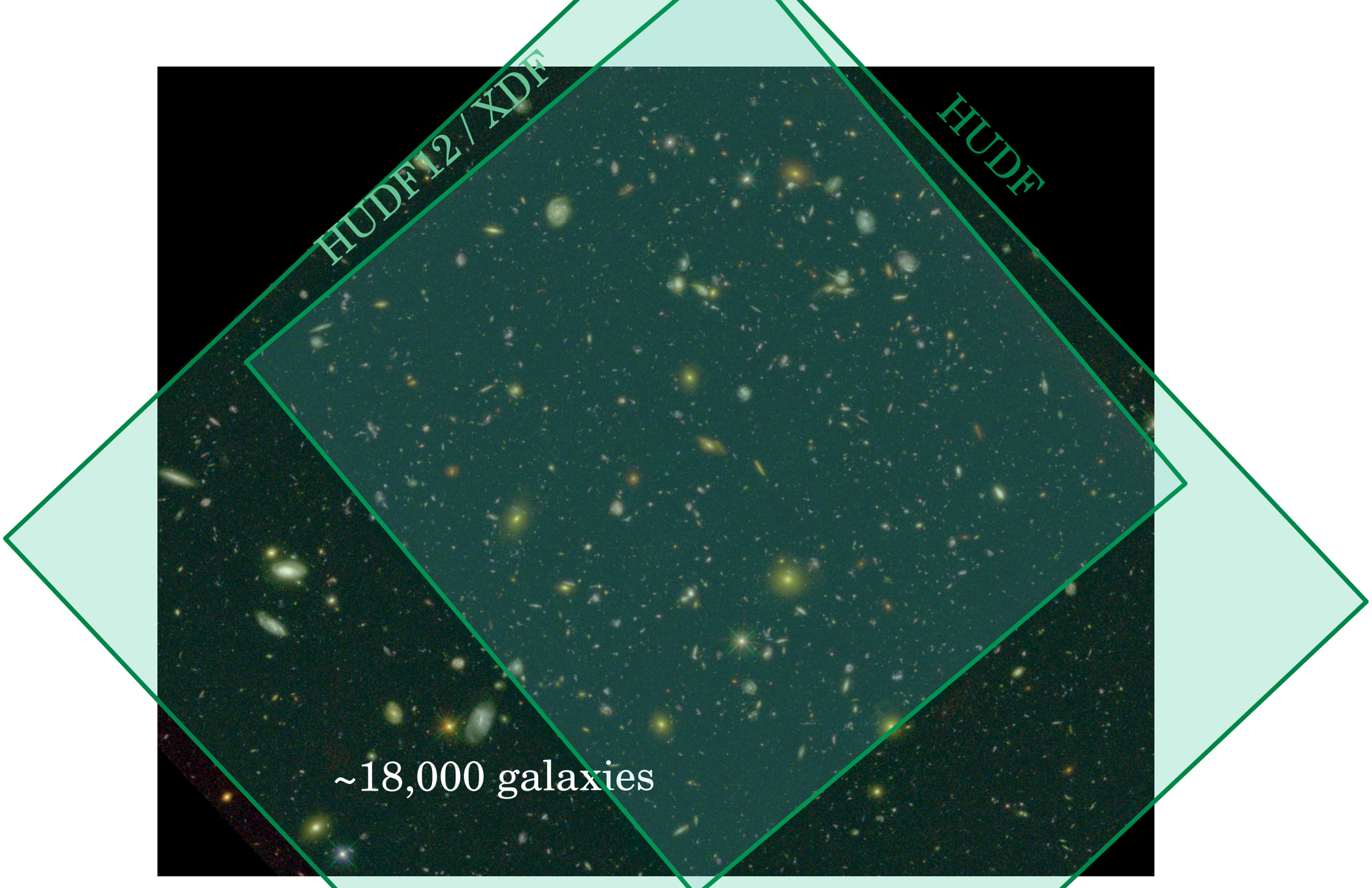
ALMA SPECtroscopic Survey in the HUDF

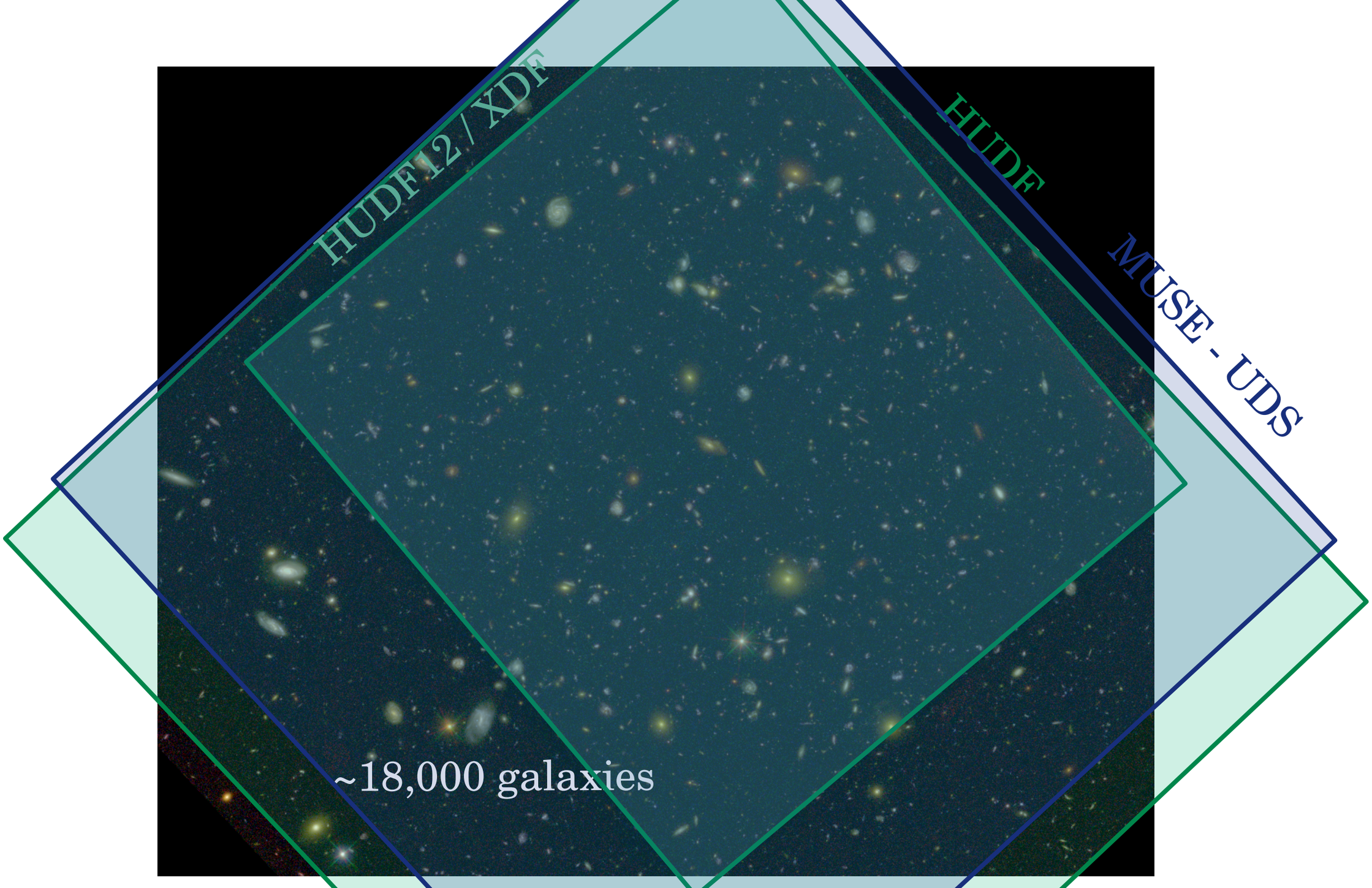
ASPECS LP:
ALMA Large Program
(150 hr)

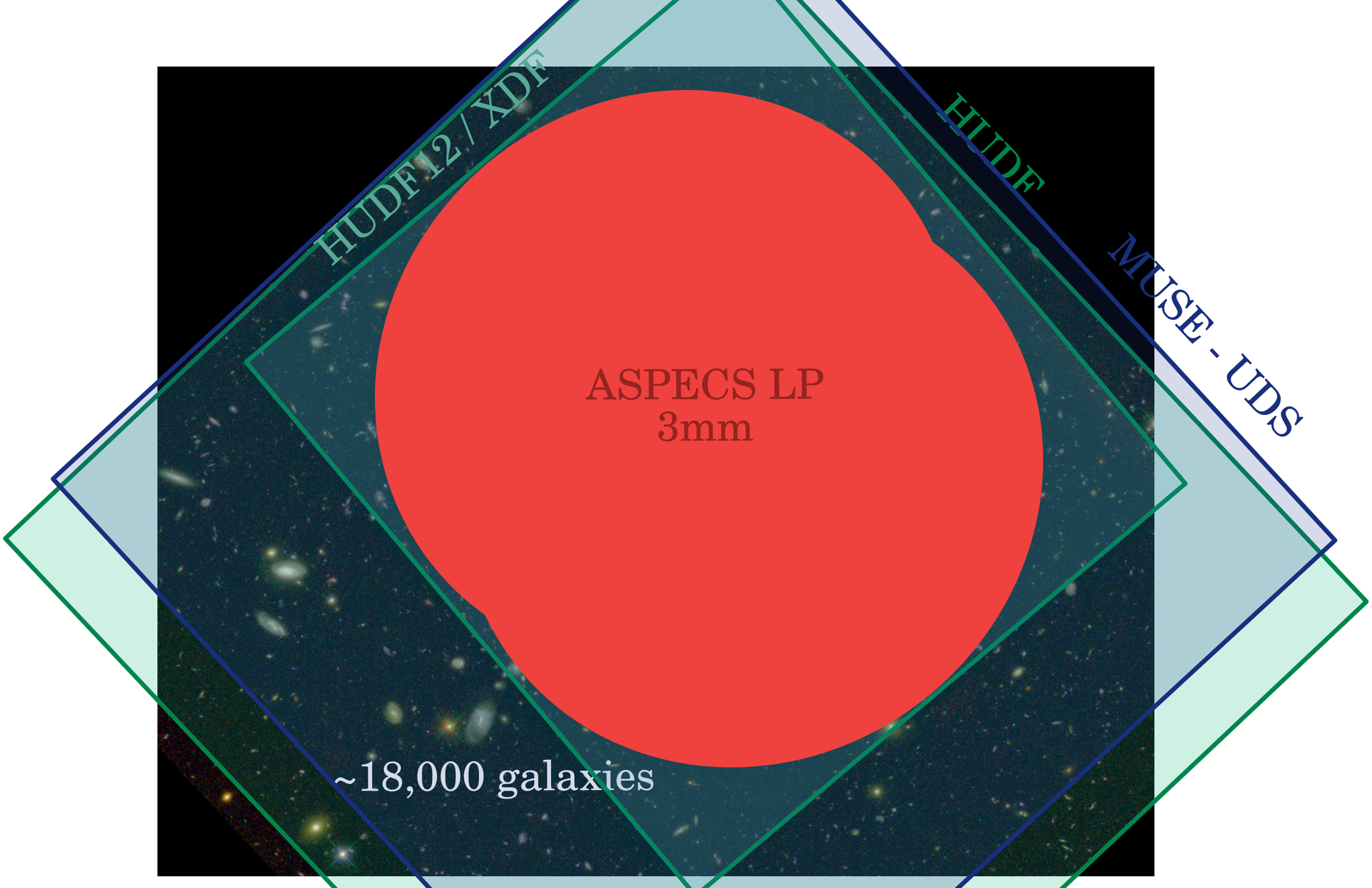
5 frequency settings @ 3mm
8 frequency settings @ 1.2mm

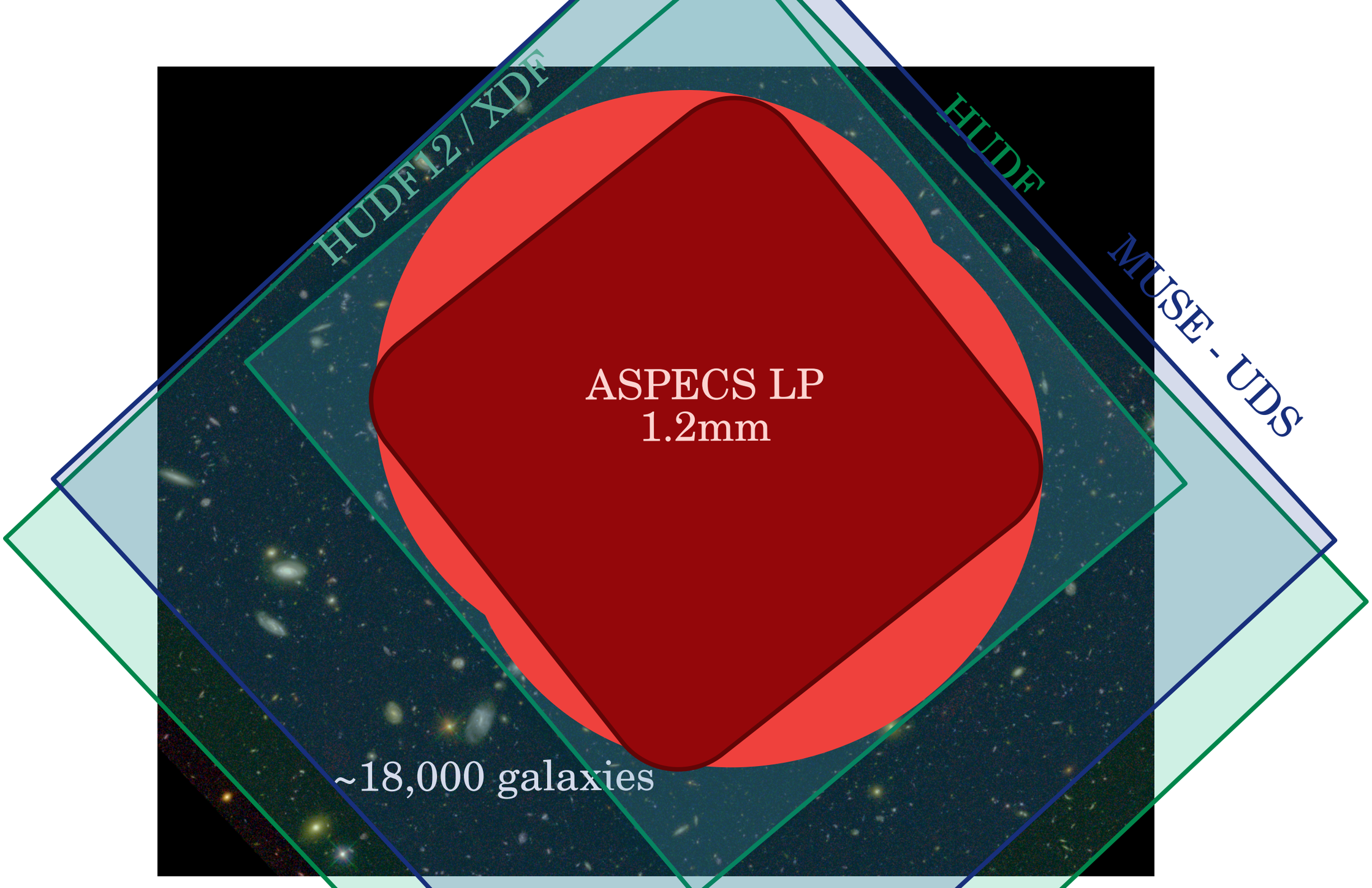



HUDF
~18,000 galaxies

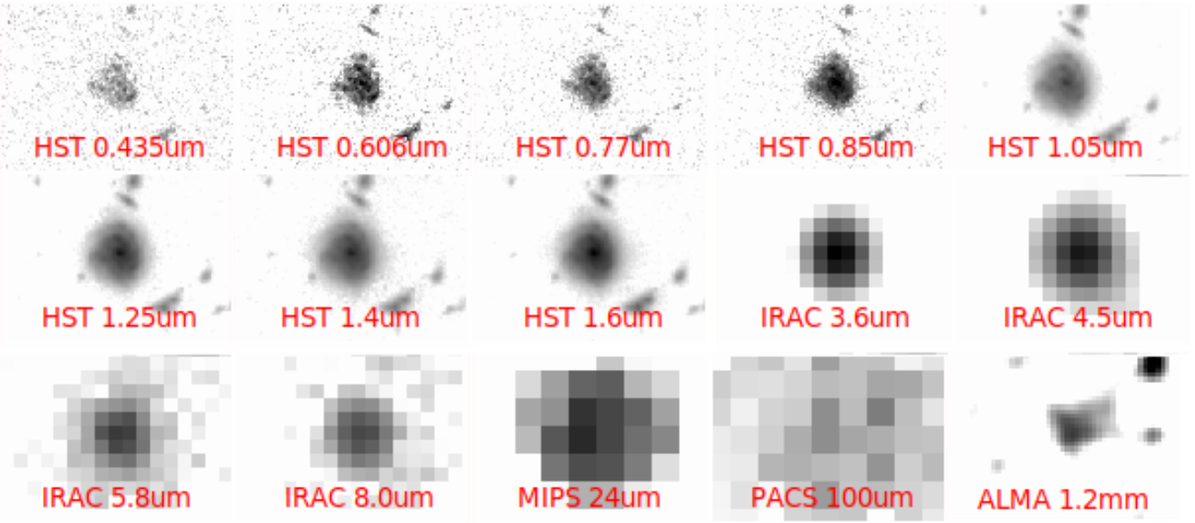

HUDF12 / XDF
HUDF
~18,000 galaxies


HUDF12 / XDF
HUDF
MUSE - UDS
~18,000 galaxies

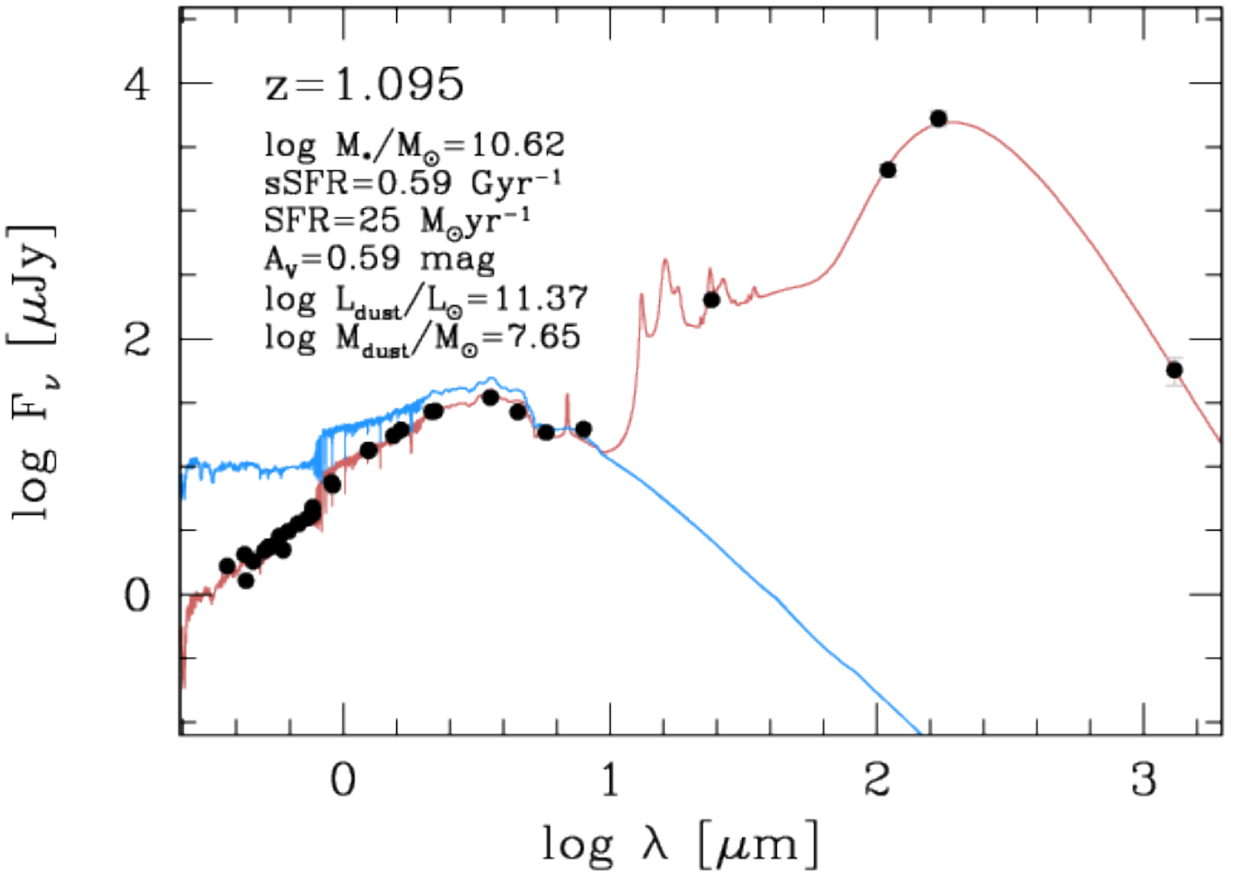

HUDF12 / XDF
HUDF
MUSE - UDS
ASPECS LP
3mm
~18,000 galaxies

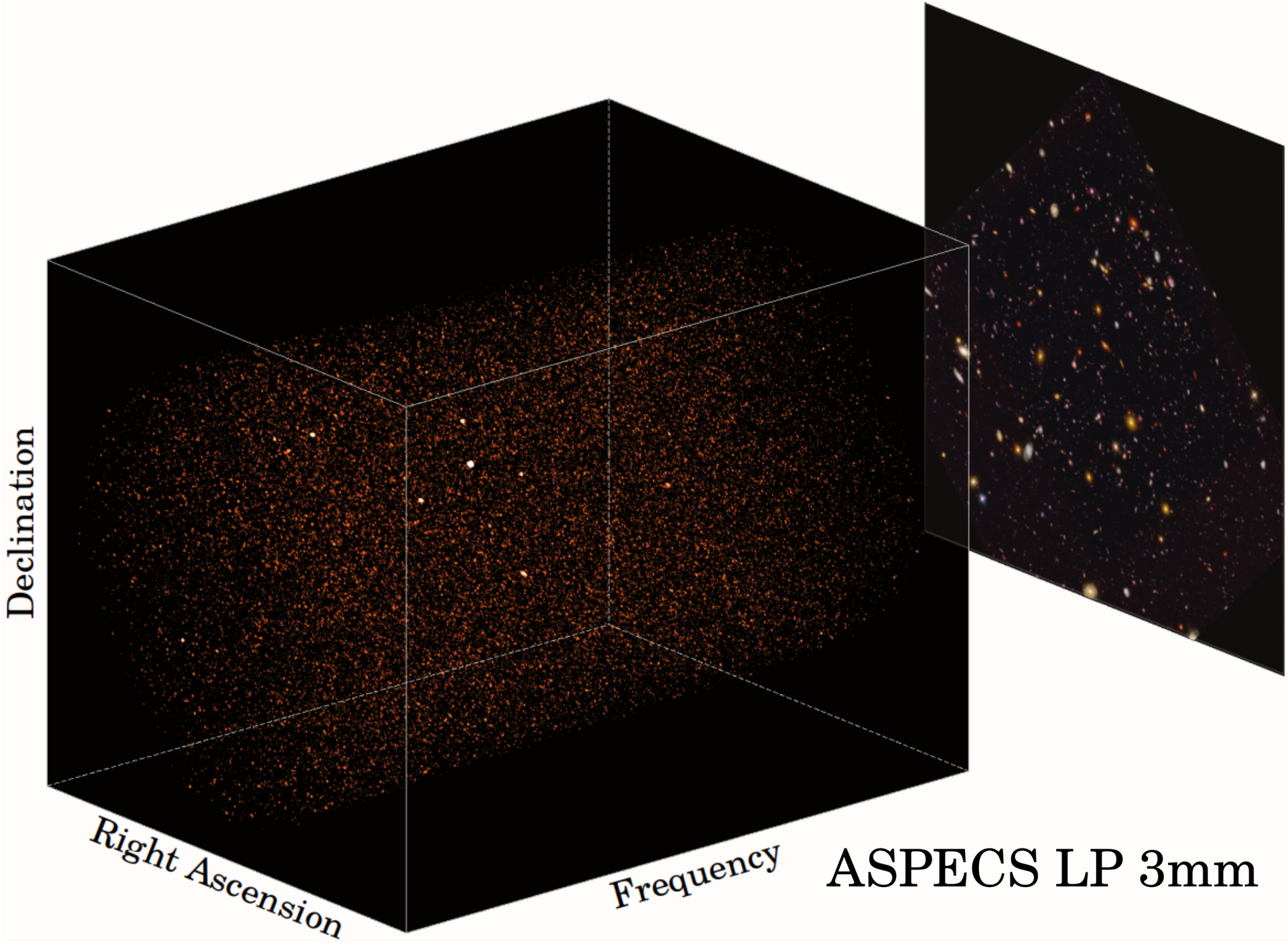

HUDF12 / XDF
HUDF
MUSE - UDS
ASPECS LP
1.2mm
~18,000 galaxies

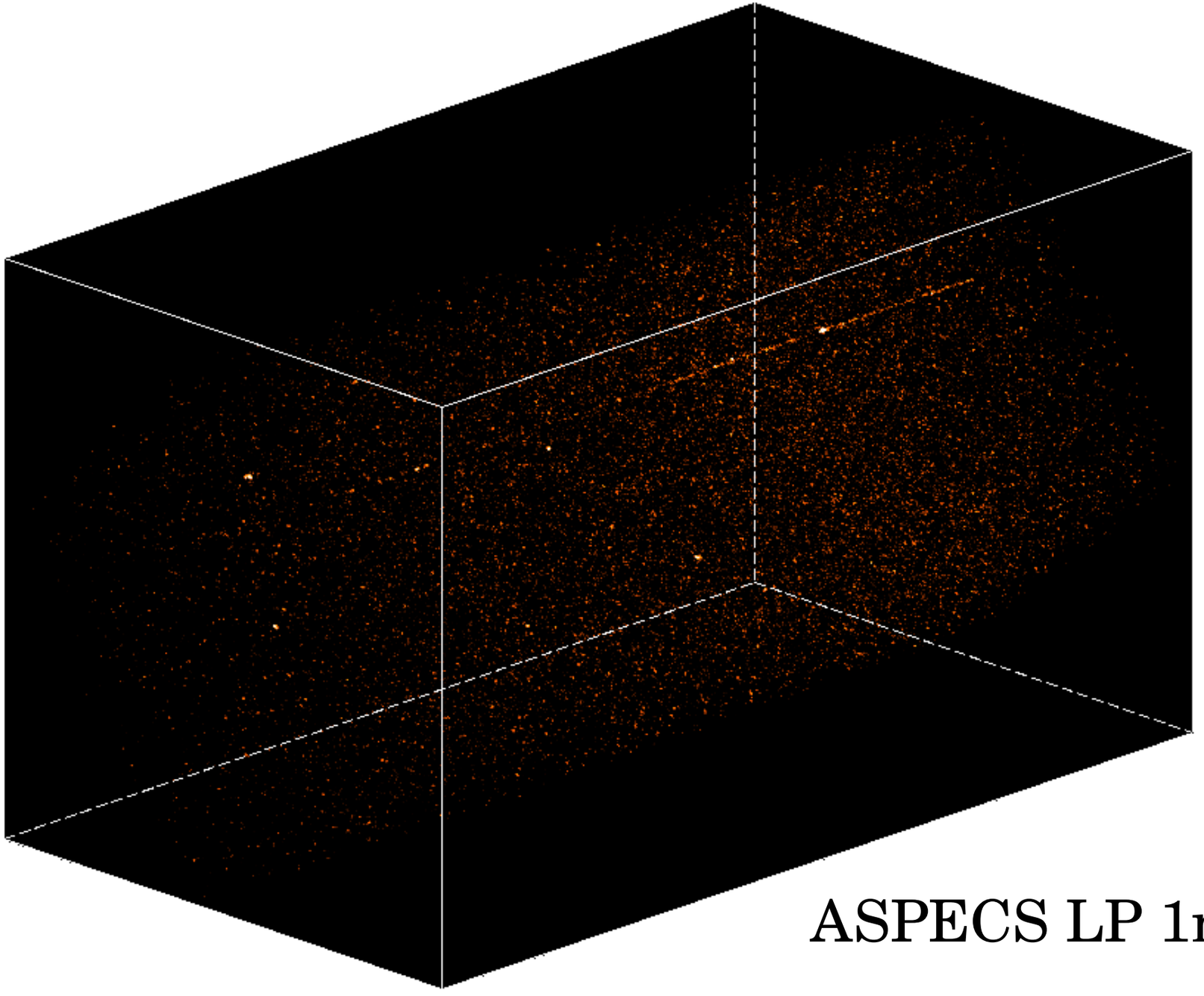
Wealth of multi-wavelength data



Example of multi-λ SED



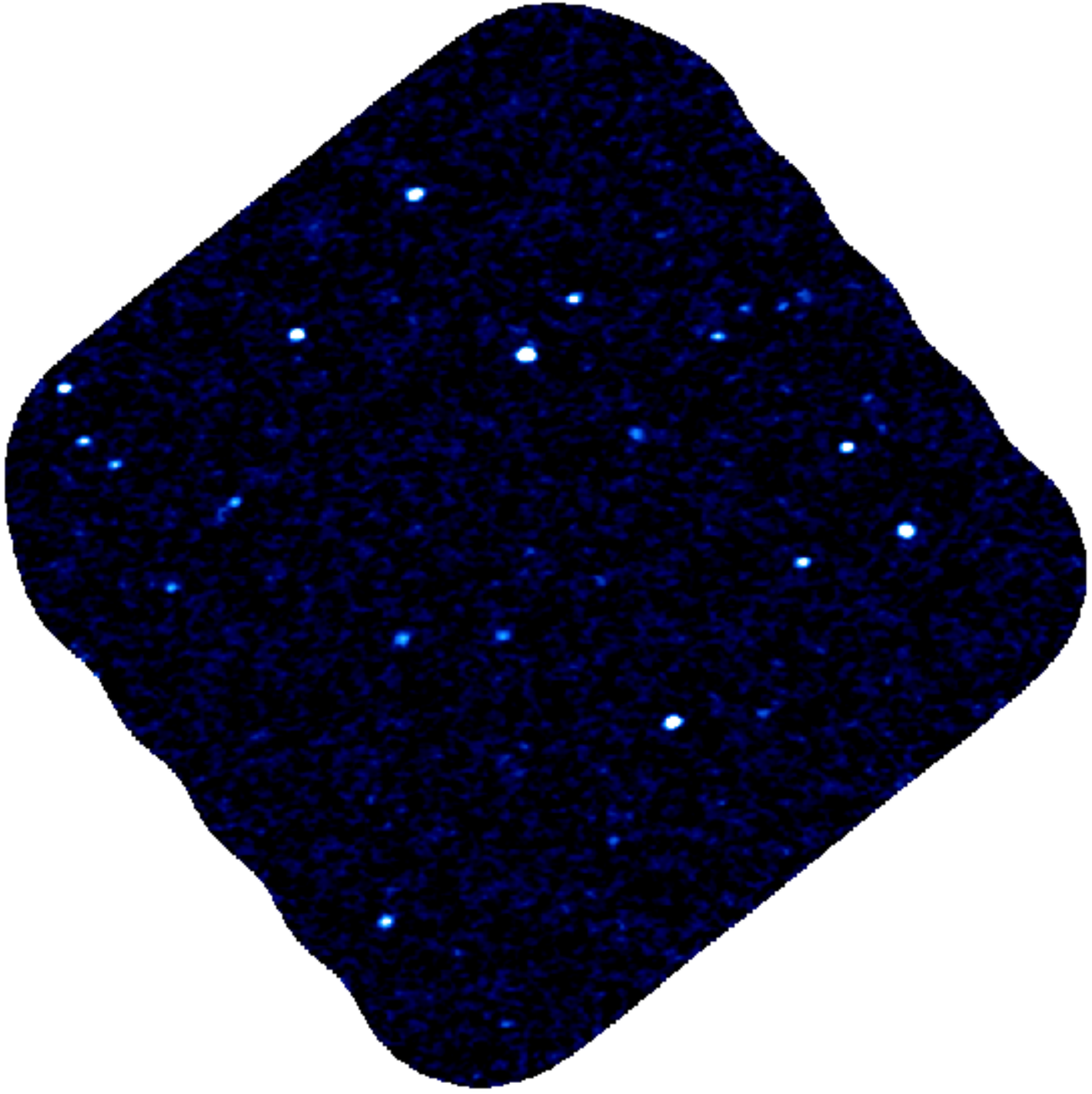

Declination
Right Ascension
Frequency
ASPECS LP 3mm



ASPECS LP 1mm

The deepest 1.2mm continuum map ever

Collapsed 1.2mm cube =>
9.3 μJy/beam continuum

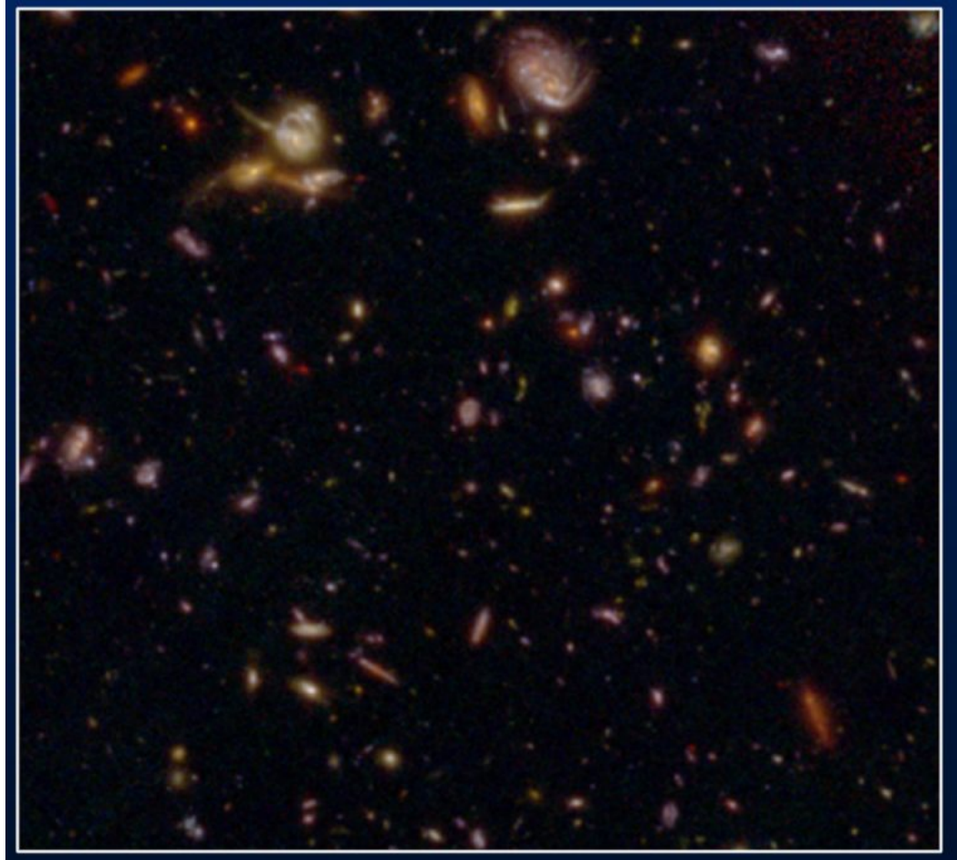


The ALMA Spectroscopic Survey of the Hubble Ultra Deep Field

Pinpointing distant dusty galaxies

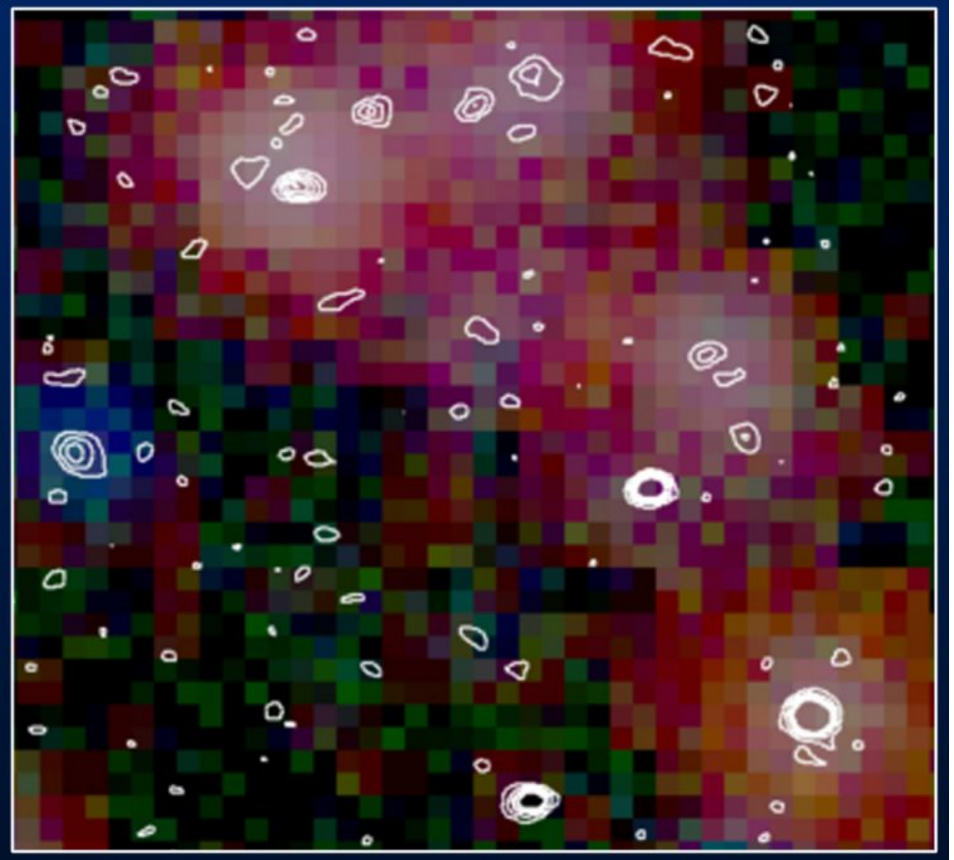
SPECS

Hubble Space Telescope



HST filters: F105W F775W F435W

Spitzer/Herschel Space Telescope with ALMA contours

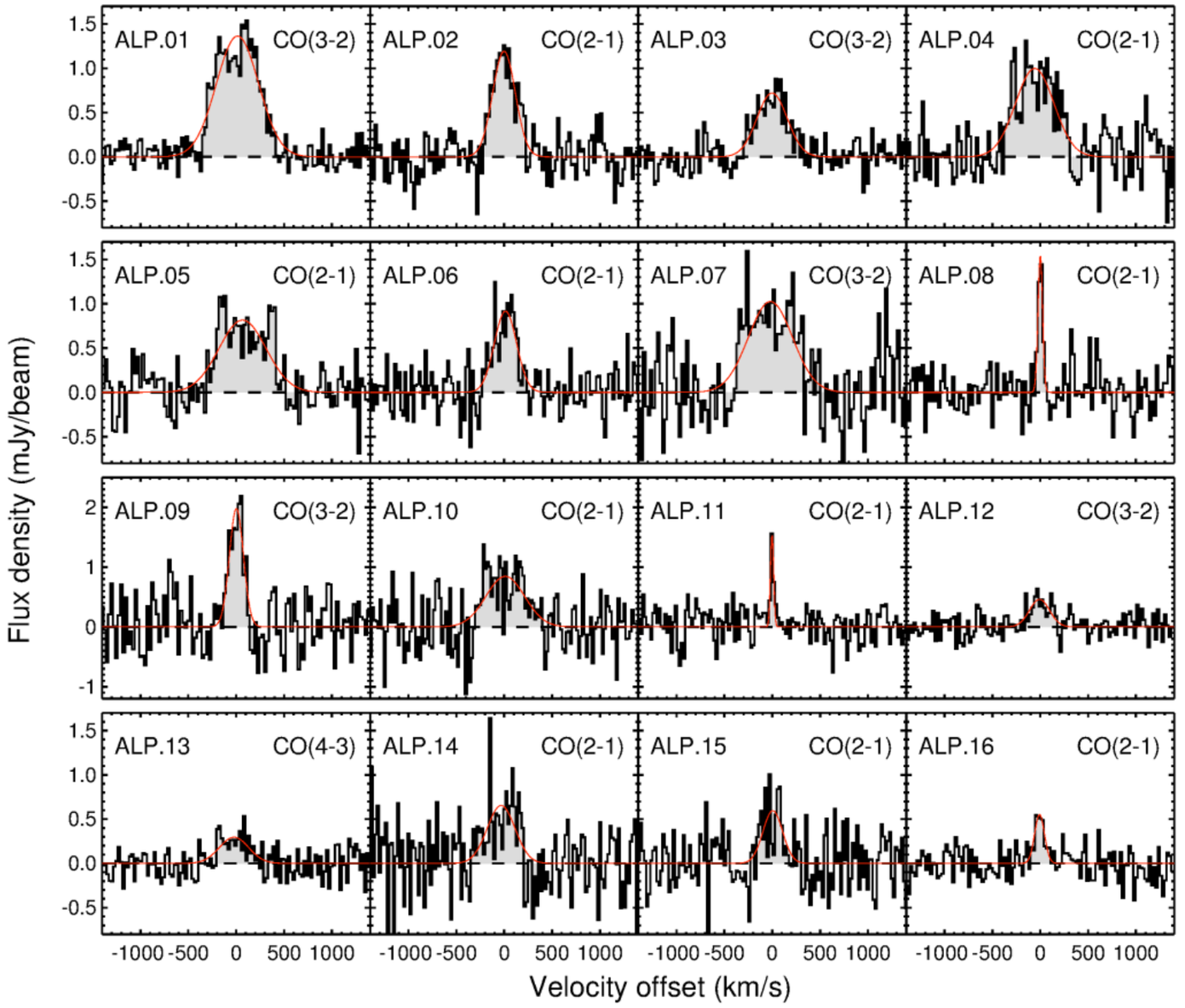


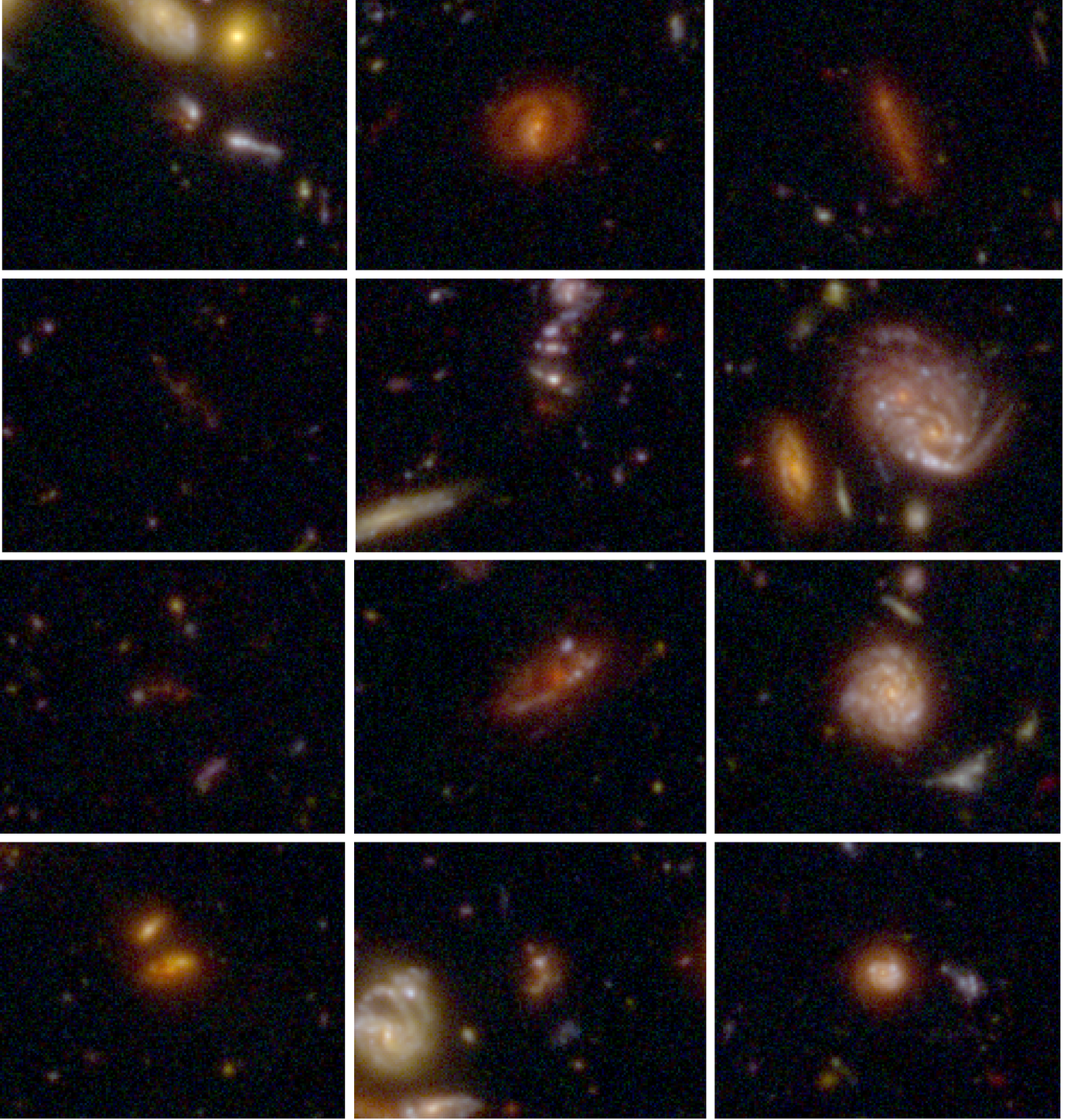
MIPS24μm PACS 100μm PACS 160μm

Image credits: STScI, Elbaz et al. 2011, Aravena et al. 2020

lines from blind search @ 3mm

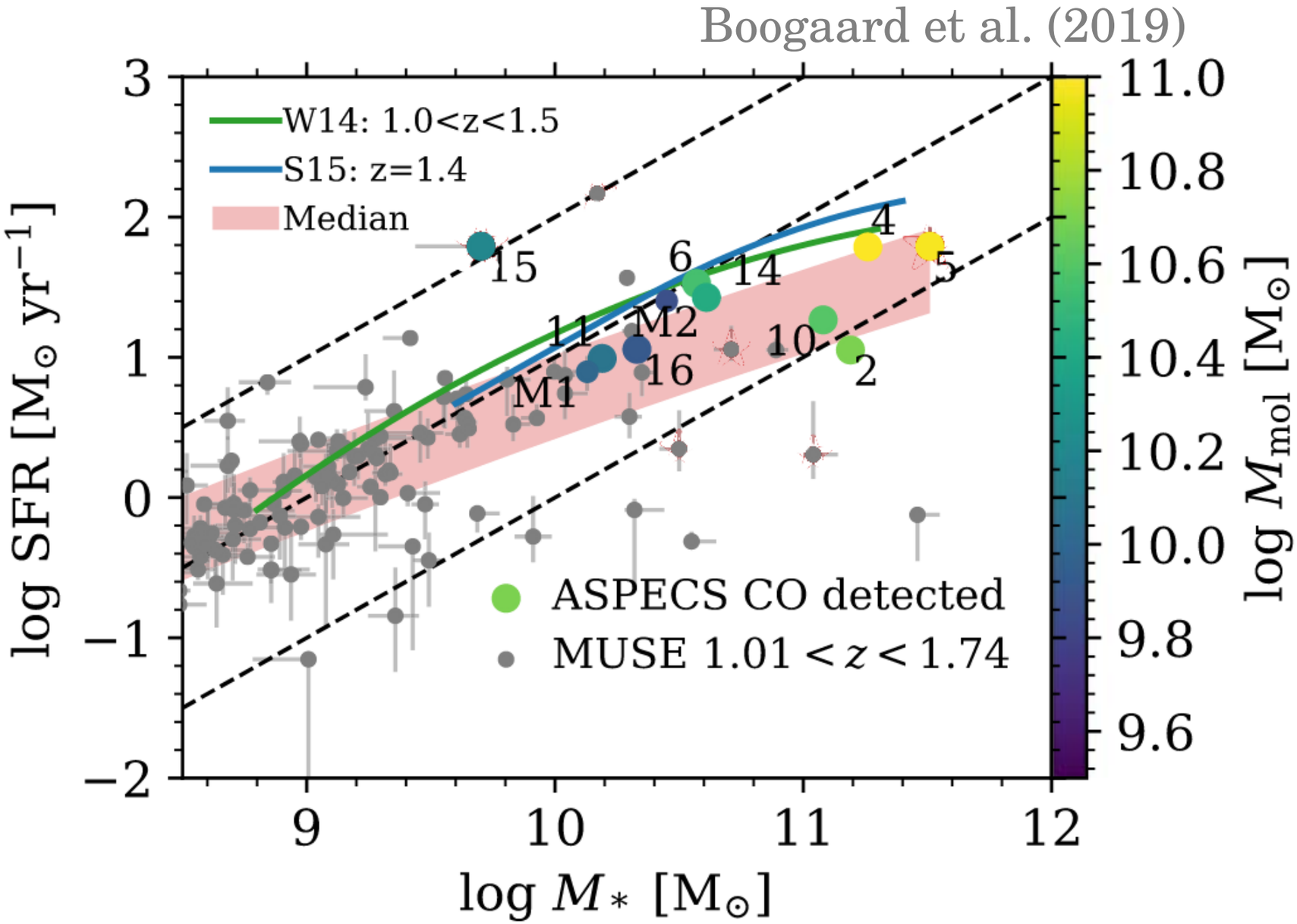
Aravena, et al. (2019)





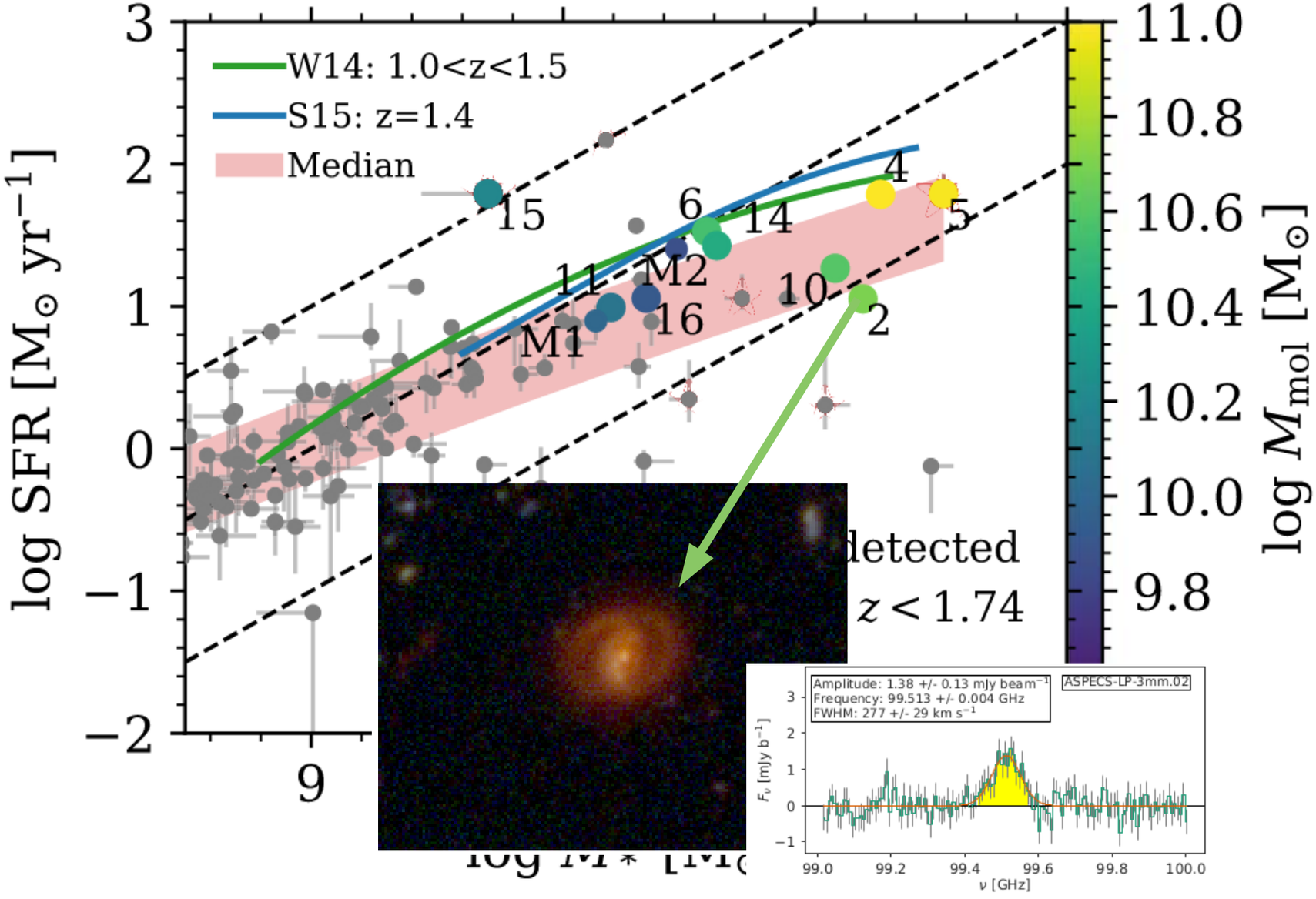
Credits: STScI, ASPECS Team

Position wrt Main Sequence

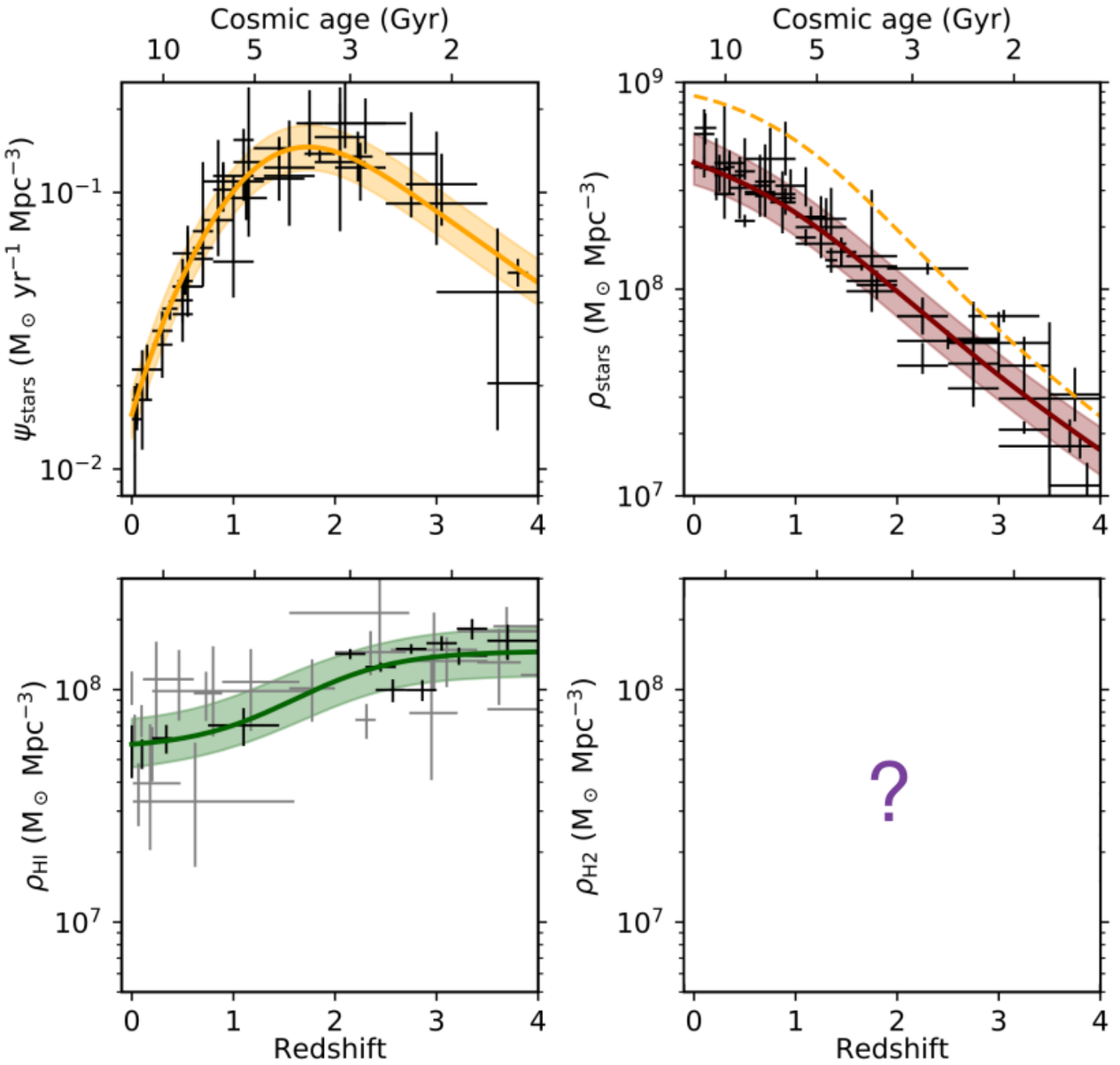


Position wrt Main Sequence

Boogaard et al. (2019)



What drives the Cosmic Star Formation History?



star formation rate density

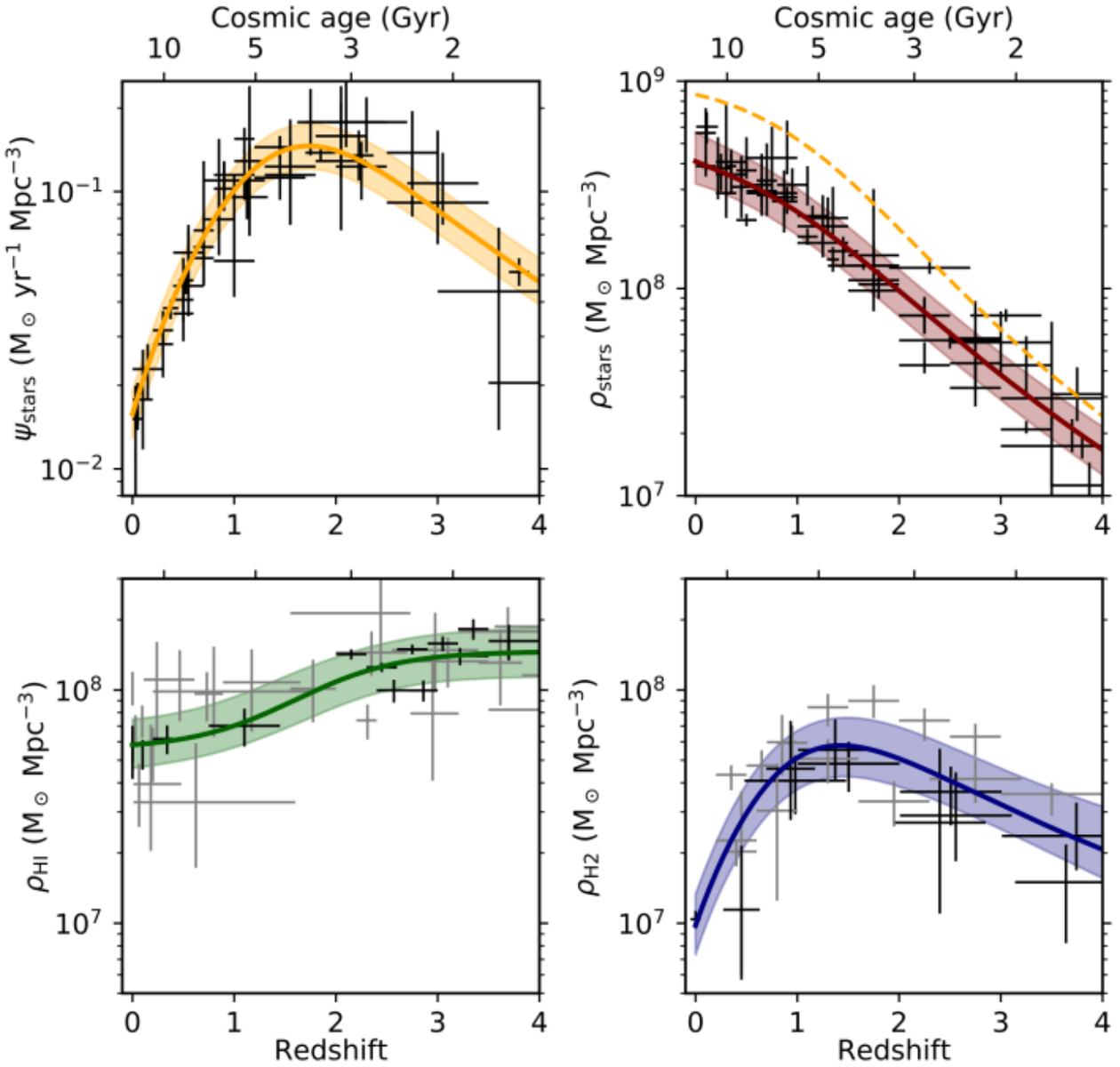
stellar mass density

atomic hydrogen density

molecular gas density

e.g., Madau & Dickinson 2014, Neeleman et al. 2017

What drives the Cosmic Star Formation History?



star formation rate density

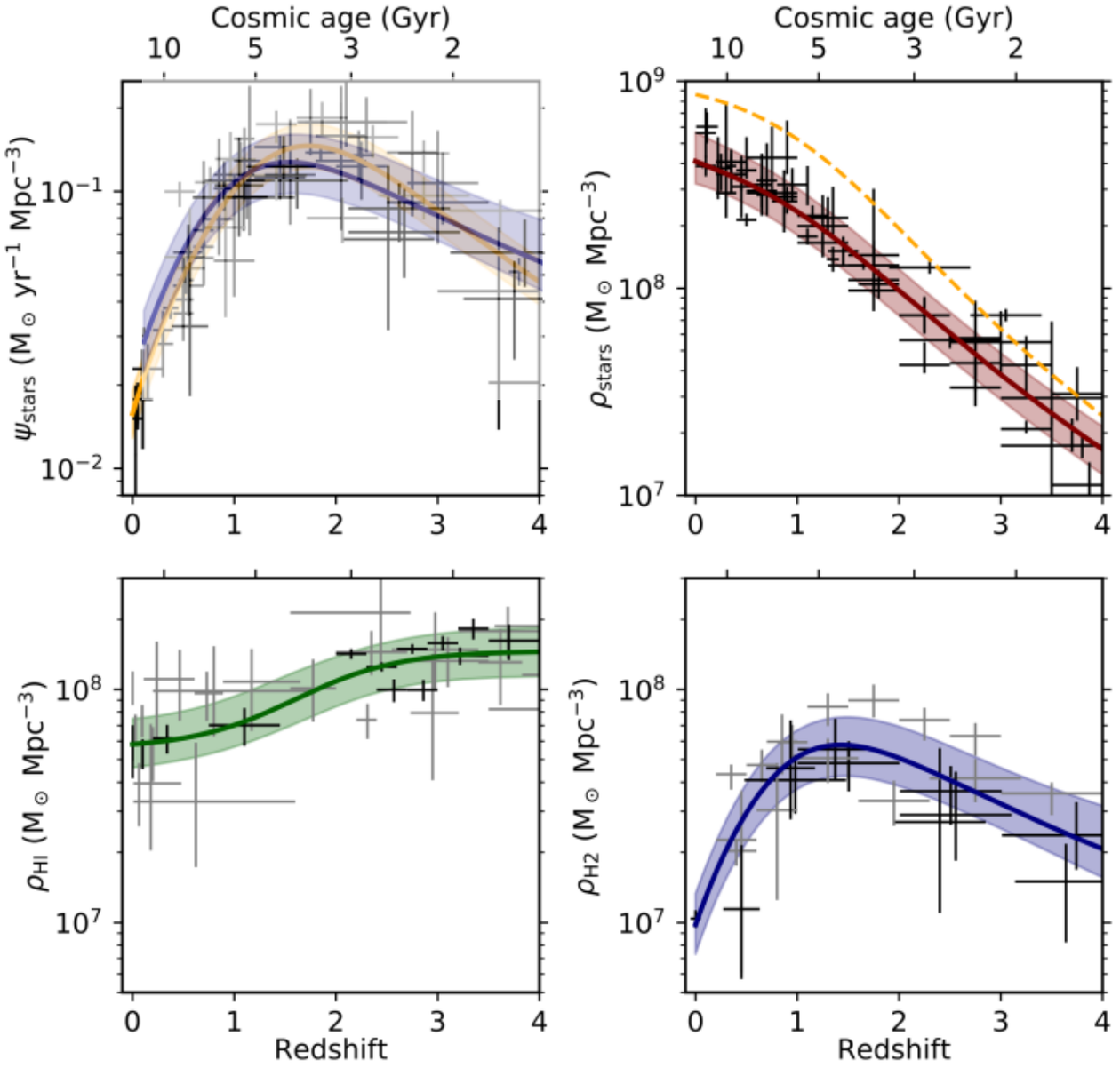
stellar mass density

atomic hydrogen density

molecular gas density

Walter et al. 2020

What drives the Cosmic Star Formation History?



star formation rate density

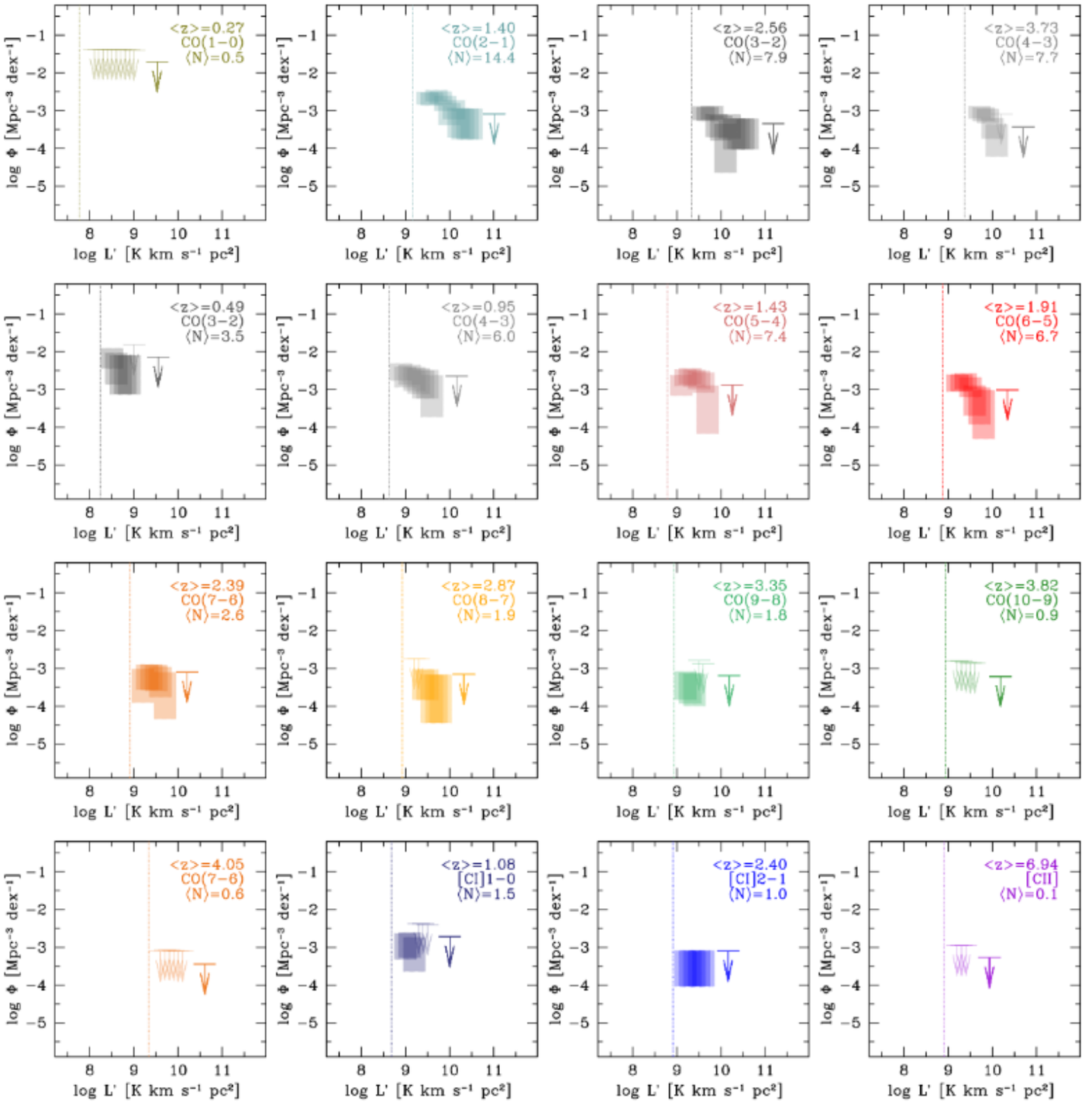
stellar mass density

atomic hydrogen density

molecular gas density

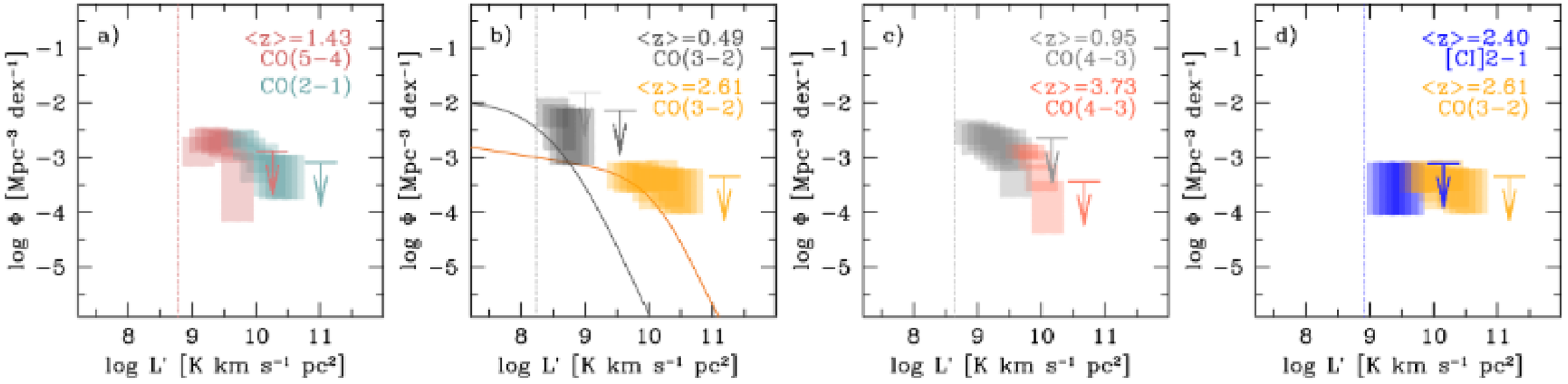
Walter et al. 2020

Luminosity functions



Decarli et al. (2020)

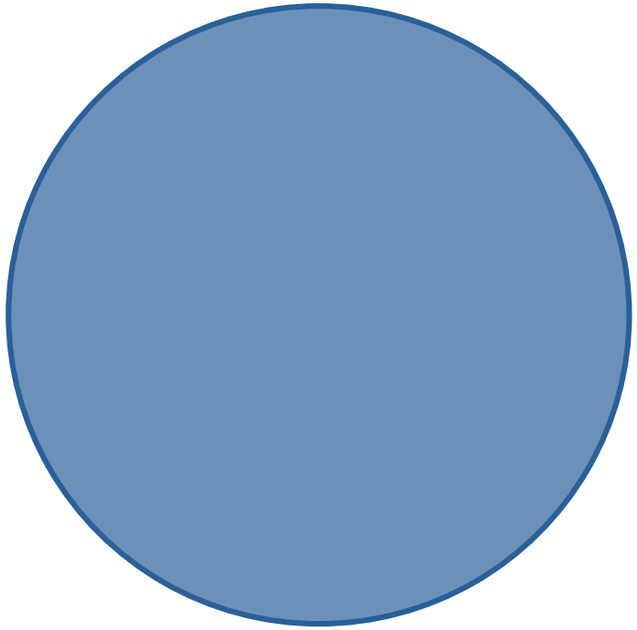
Luminosity functions



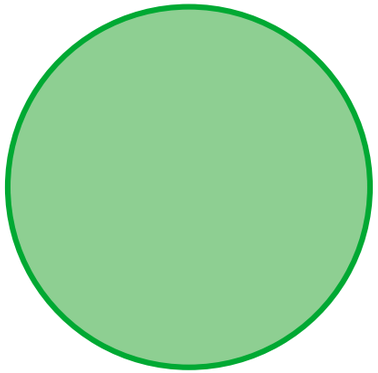
Decarli et al. (2020)

The next step: molecular deep fields with the ngVLA

The next step: molecular deep fields with the ngVLA



ngVLA FoV
@27 GHz: 2.1’

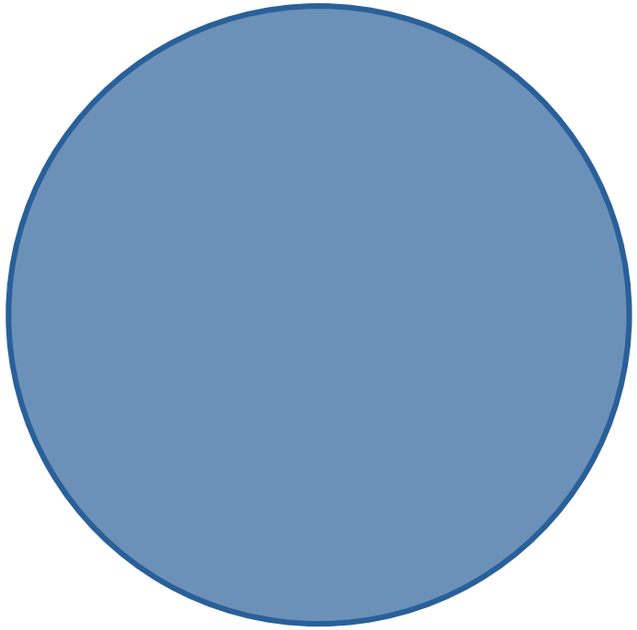


ALMA FoV
@90 GHz: 1.2’

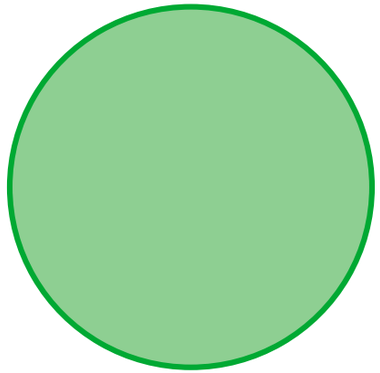
The next step: molecular deep fields with the ngVLA

ALMA bandwidth @90 GHz: 1:12

ngVLA bandwidth @27 GHz: 1:3



ngVLA FoV
@27 GHz: 2.1’

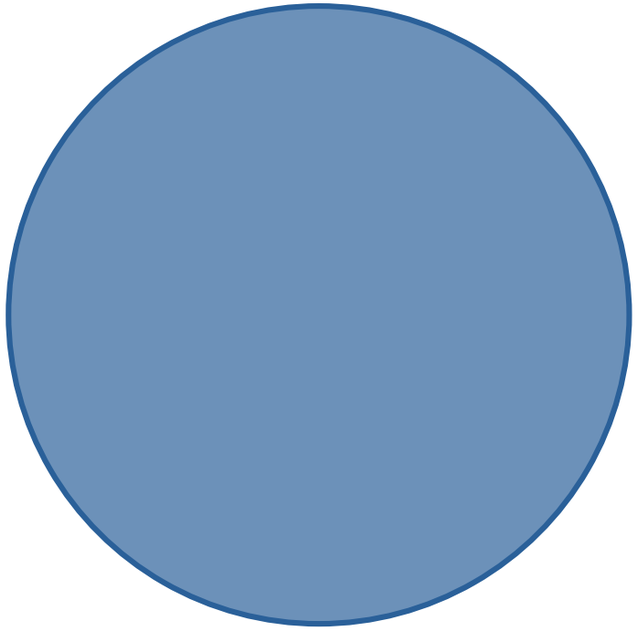


ALMA FoV
@90 GHz: 1.2’

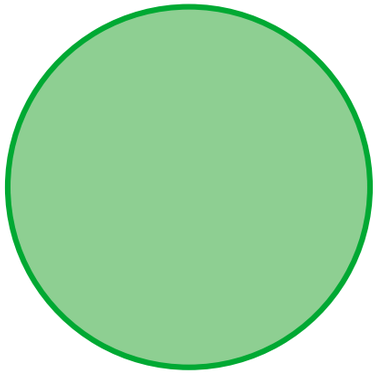
The next step: molecular deep fields with the ngVLA

ALMA bandwidth @90 GHz: 1:12

ngVLA bandwidth @27 GHz: 1:3

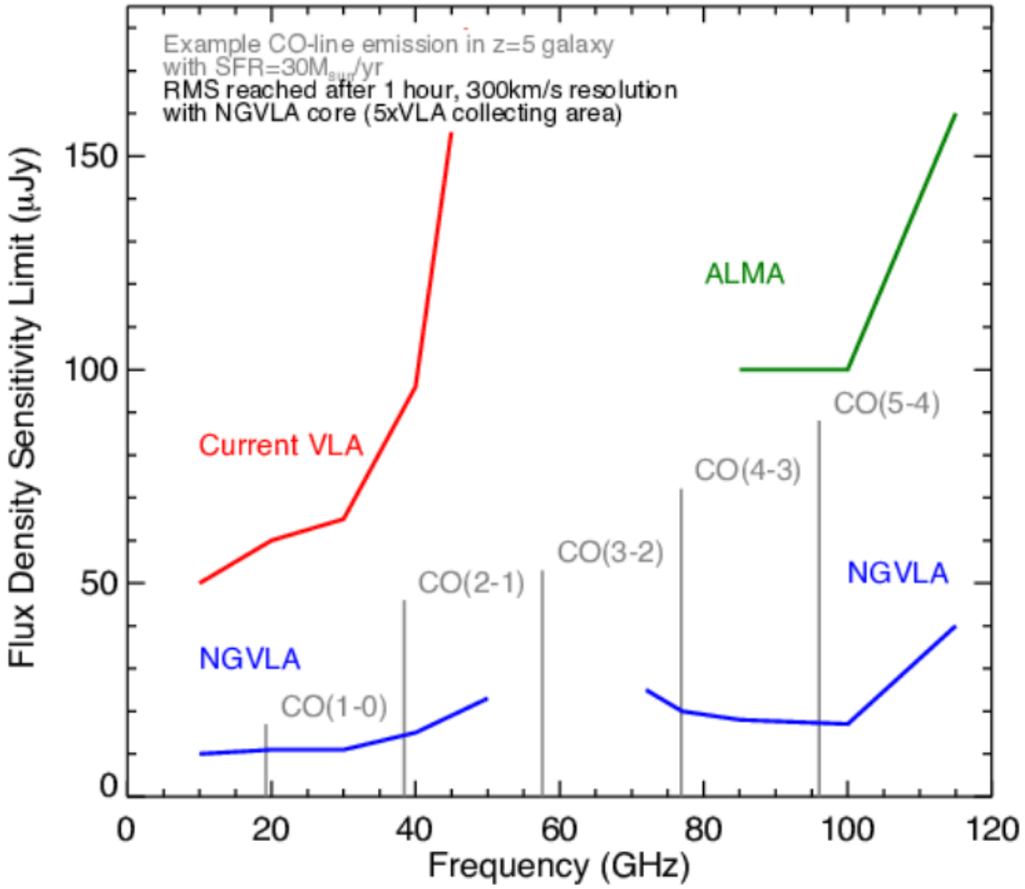


ngVLA FoV
@27 GHz: 2.1’

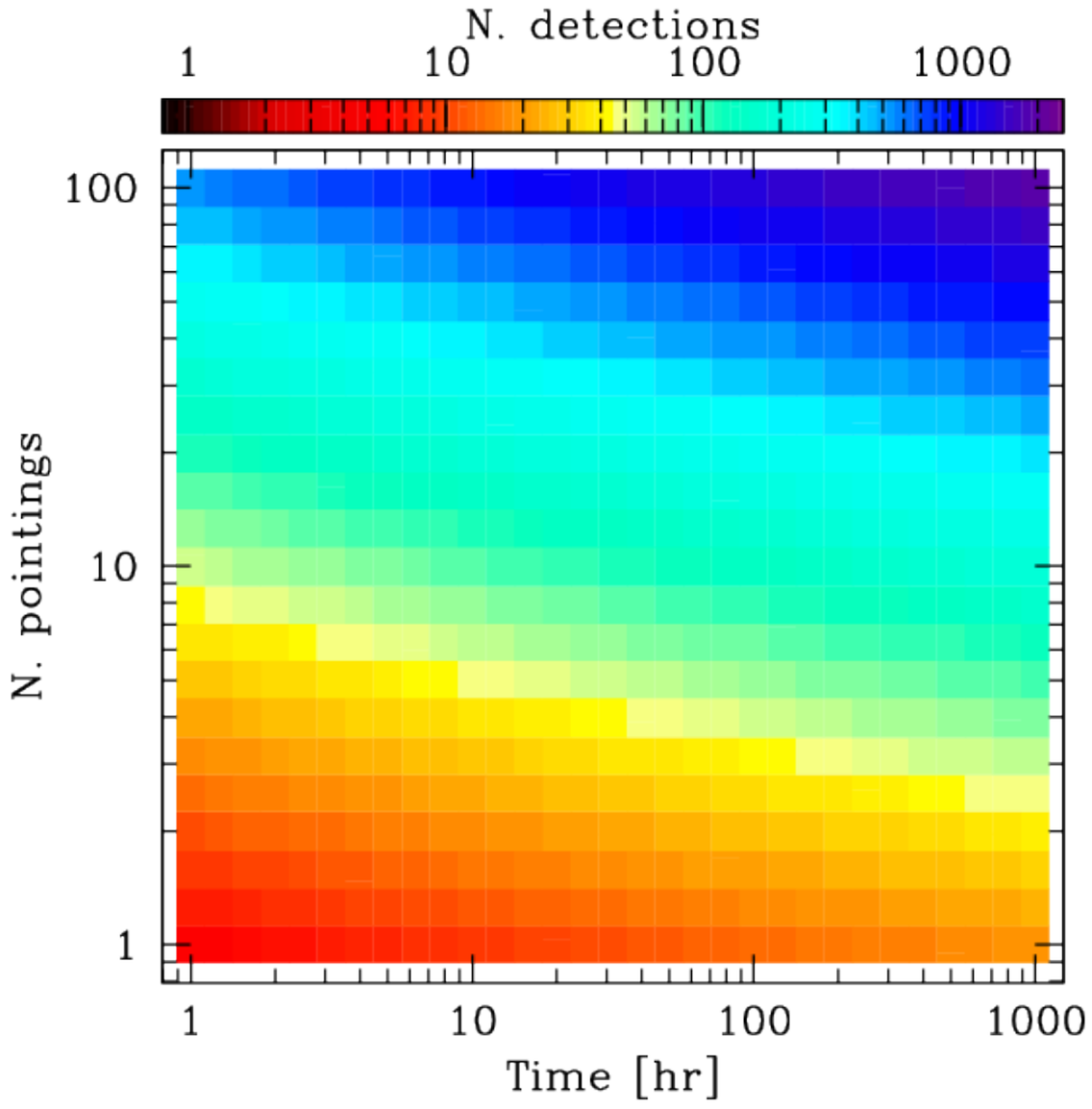


ALMA FoV
@90 GHz: 1.2’

Casey et al. (2015), Decarli et al. (2019)



The next step: molecular deep fields with the ngVLA



2.5<z<3.5

S/N>5

FWHM=200 km/s

assuming
ASPECS/COLDz LFs

See A. Bolatto's iPoster!