ALMA spectroscopic survey

COSMOS -- cosmic evolution survey
started with Hubble
    Subaru, XMM, Spitzer, Galex, VLA, ...

2 deg^2 field selected to enable BOTH VLA and ALMA

COSMOS ==> enormous a priori information :
    x-ray, UV, opt, IR, radio photometry
    HST 0.07 arcsec imaging
    photometric redshifts for ~800,000 galaxies
    spect-z for 35,000
Cosmos Survey

2 deg$^2$
Motivation:

in early universe much of galaxy evolution driven by merging and interactions

requires: large areas to sample all environments rich clusters, voids, filaments multi-lambda to sample all phenomena

Antennae galaxies -- NGC 4038, 4039
Galaxy Formation / Evolution:

- hierarchical growth of dark matter halos, accretion and merging
- cooling / condensation of gas into protogalaxies -- $\Rightarrow$ primordial spheroids, starburst disks
- feedback -- starburst & AGN winds & UV
- galactic interactions & merging
  $\Rightarrow$ starbursts, AGN feeding
  $\Rightarrow$ galaxy growth & morphological transformation

Evolution (z & environment) --
  envir. more critical than redshift
Coupled evolution of LSS, galaxies, star formation, AGN w/ z

redshift slice from $\Lambda$ CDM sim.

$z=1, \Delta z=0.02$

90 Mpc

1°4
Major features of COSMOS survey:

• large area -- 1.4 x 1.4 deg
  => cover largest large scale structures

• high sensitivity
  => morphology of L* galaxies at z < 2

• sensitivity + area
  => 2x10^6 galaxies ==> like SDSS at z > 0.5

• equatorial  => multi-λ obs. from all tel.
Lookback 2 - 10 Gyr

covers vol ~ SDSS at z ~1
COSMOS ACS coverage

Cycle 12 & 13
590 orbits

NICMOS-3
1.6 µm -- 25mag
~7% of area
Subaru SCAM
PI: Taniguchi
25 nights
26 - 28 mag 5σ
XMM
PI : Hasinger
1.4 Msec
VLA
PI : Schinnerer
300 hrs
7-10 µJy
COSMOS 20 band photometric redshifts:

\[ \Delta z / (1+z) = 0.05, 0.15 \]

\[ \sigma_z / (1+z) = 0.02 !!! \]

to \( z \sim 3 \) at 24 mag

Mobasher et al.
structures/cluster identification:

• adaptive smoothing
  
  avoid a priori assumptions
  
  w.r.t. shapes and sizes
  
adjust spatial smoothing filter to the local SNR

  small filter width ==> high density region
  
  larger filter ==> low density, extended regions
galaxies w/i
redshift slices w/ $\Delta z = 0.1$
all LSS projected on line of sight:
phot-$z$ $\Rightarrow$ SED type, stellar mass, $M_V$

luminous early-type $\Rightarrow$ dense core of LSS

$M_* = 3 \times 10^{13} M_{\odot}$!
COSMOS structures probe Dark Matter predictions of $\Lambda$CDM simulations:

1) mass distrib. of halos
2) galaxy occupation vs halo mass/size
3) relative areas / volumes as fn. of density as fn. of $z$

area filling as fn. of density and $z \Rightarrow$
area/vol. (overdensity):

$\Sigma_{\text{galaxies}} / \langle \Sigma_{\text{galaxies}} \rangle$

Low z  High z  All z

$z = 0.2 - 1.1$
$z = 0.2 - 0.5$
$z = 0.5 - 1.1$

$10^2$
$10^0$
$10^{-2}$
$10^{-4}$

% of area

$\Sigma_{\text{galaxies}} / \langle \Sigma_{\text{galaxies}} \rangle$

$0 5 10 15 20 25 30 35$

$\Rightarrow$ see growth of high density structures!!
Weak lensing

$\Rightarrow$ overall mass distribution (dark matter)

HST ACS images $\Rightarrow$ distorted shapes of background gal.

extremely difficult (few %) -- must correct for HST psf var.
over field and as fn. of time

Massey, Rhodes, Leauthaud …
WL mass map vs LSS galaxy overdensity map:

projected DM mass distribution

galaxy overdensities
DM mass map vs X-ray (XMM)

X-ray:
Hasinger, Finoguenov …
Contours: lensing DM

Red: x-ray

Blue: galaxy mass density
QuickTime® and a YUV420 codec decompressor are needed to see this picture.

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Galactic Evolution (z, environment):

- galaxy colors $\Rightarrow$
  - ages of stellar pop. vs environment

- stellar mass $\Rightarrow$
  - buildup of massive gal. in LSS

- star formation rates (SFR) as fn. of z and LSS
SFR decreases at later epoch and at high density

\[ \tau_{\text{SF}} = \frac{M_*}{\text{SFR}} \]

\[ \text{SFR} \]

\[ \text{SFR} / \text{mass} \sim \text{constant}, \text{ down to last 4 Gyr} \]
normalize SFR to Hubble time

\[ \Rightarrow \frac{\tau_{\text{SF}}}{\tau_{\text{cosmic}}} \]

call this -- the \textbf{Maturity} (\(\mu\)) -- \(\mu << 1 \Rightarrow \text{youthful}\)
\(\mu >> 1 \Rightarrow \text{mid/old age}\)

e.g. \text{galaxy just starting to undergo SF},
\[ \tau_{\text{SF}} << \tau_{\text{cosmic}} \Rightarrow \mu << 1 \Rightarrow \text{youth} \]

galaxy which formed star long ago and stopped,
present SFR small compared to \(M_\ast / \tau_{\text{cosmic}}\)

\[ \Rightarrow \tau_{\text{SF}} >> \tau_{\text{cosmic}} \Rightarrow \mu >> 1 \Rightarrow \text{old} \]

gal. form star early (\(\mu >> 1\))
\(\mathcal{SB} \Rightarrow \mu \quad \text{(rejuvenation)}\)
\(\mu \quad \text{(rejuvenation short-lived)}\)
Z = 1.

lowest, z = 0.3
Merger rate evolution:

Very strong evolution of merger rate.
mm/submm imaging - CARMA and ALMA

- gas mass -- $M_{\text{H}_2}$
- dynamical mass -- $M_{\text{dyn}}$
- evolutionary state -- $M_{\text{H}_2}/M_{\text{dyn}}$
- SFR -- IR continuum & CII

ALMA sensitivity

spectroscopy -- few hr

  $\Rightarrow$ typical gal. w/ 0.5 -- 1 arcsec res.

continuum -- 15 sec $\Rightarrow 5\sigma = 2 \text{ mJy @ 345 Ghz (1mm)}$

$\Rightarrow \sim 3000$ sources w/i COSMOS field (1 week)
SFR:

multi-band continuum detections $\Rightarrow$ separation of
non-thermal synchrotron $\sim \nu^{-0.7}$
free-free $\sim \nu^{-0.1}$
dust $\sim \nu^3 \Rightarrow 4$
free-free $\Rightarrow$ SFR$_{\text{OB}}$ (10$^7$ yrs)

H2 masses:

CO-to-H2 conversion factor:
multi-trans. + isotopes
dust emission -- use Spitzer + Herschel to get $T_d$

Maturity:

$M_{\text{dyn}}/M_{\text{H2}} = 1$ (young) $\Rightarrow$ 10 (old, like MW)
How deep to go?

Want to go significantly below $M_\ast$:
1) number increase rapidly
2) evolution in slope and $M_\ast$

$\Rightarrow$ $H_2$ masses

$3 \times 10^9 \text{ -- } 3 \times 10^{10} M_{\text{sun}}$
Targeted imaging of COSMOS clusters:

many galaxies w/i beam at similar z

10 arcmin² mosaic ==> 100 -- 1000 galaxies

environment determined from opt. imaging

correlate maturity and $M_{\text{gal}}$ w/ environment
in COSMOS, seeing expected evolutionary trends:

• see LSS extending ~20 Mpc (galaxy counts and DM- weak lensing)

• evolution of bias (concentrations of galaxies) w/ time

• massive, early types in dense regions

• increase in merger rate ~ (1+z)^6-8

ALMA critical:

probes active SF ISM <=< dynamically driven starbursts / AGN

dynamics ==> total mass & gas mass fraction
Abell 2218

0.15 Jy km/s (corrected for magnification)

$\Rightarrow$ H2 = $2 \times 10^{10}$ $M_{\text{sun}}$

850 µm
Test of adaptive smoothing:

- ~50% of gal. w/i structures
- ~50% in field

- recovers all significant structures
- retains power on all scales
- no spurious recoveries
- conserves number counts