Cosmic Evolution of Gas and Dust
ALMA @ 5 years

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ionized gas: HII regions
far-IR/submm: dust reprocessed UV
star formation rate

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What we have learned.

Resolved dust continuum and submm spectra of highly lensed DSFGs.

Resolved dust emission for 100-1000 unlensed DSFGs.

CII emission at very high redshifts: a dynamic tracer in the absence of IR luminosity?

(and what we have yet to do)
SPT: Resolved dust continuum and submm spectra of highly lensed DSFGs.

Vieira et al. (2013)
SPT: Resolved dust continuum and submm spectra of highly lensed DSFGs.
SPT redshift distribution has interesting implications for the total star-formation rate density beyond $z \sim 3$. 

Plot from Casey, Narayanan & Cooray (2014); Data from Weiss et al. (2013)
Confirming redshifts via CO spectral scans isn’t yet efficient for large, unlensed samples.

Even the best photometric redshifts can fail catastrophically: differential attenuation, decoupled emission from stars / dust / gas

Optical/near-infrared still most efficient redshift machines: yet only ~30–50% complete!

A major limitation for z>3 samples.
Dust continuum emission: Minutes per source

Revolutionized DSFG follow-up.
Are submm multiples at the same redshift or projections?

Karim et al. (2013), Hodge et al. (2013)
Dust continuum emission: Minutes per source

Are submm multiples signatures of interactions / mergers?
Spectroscopic confirmation of known multiples is very difficult.
Motivated by these perspectives, the first science goal of the future Atacama Large Millimeter/submillimeter Array (ALMA) is to “detect spectral line emission from CO or CII in a normal galaxy like the Milky Way at a redshift of $z = 3$, in less than 24 hours of observation.” In order to translate

\[ \Phi \left[ \text{Mpc}^{-3} \text{dex}^{-1} \right] \]

\[ L_{\text{IR}} \propto L'_{\text{CO}} \]
Twelve [CII] detections at z=5.5

Less dust-enriched than similar massive galaxies at z=2. Remarkably different than Himiko (LAE), why?

Capak et al. (2015)
Extreme Galaxies to Normal Galaxies: what’s normal at high-z?
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- the shorter (~10×) gas depletion times at high redshift of all star forming galaxies, both on and above the MS, imply a more efficient mode for star formation from existing gas supplies. This is naturally a result of highly dispersive gas motions (due to prodigious on-going accretion needed to replenish gas contents and to galaxy interactions) for all high redshift galaxies – those on and above the MS.
Individual ALMA pointings currently in the archive (to 2013)
How will ALMA inform the first JWST studies?
What ALMA studies need to be done NOW in preparation?

First Light & Reionization

JWST will be a powerful time machine with infrared vision that will peer back over 13.5 billion years to see the first stars and galaxies forming out of the darkness of the early universe.

Read More

Assembly of Galaxies

JWST's unprecedented infrared sensitivity will help astronomers to compare the faintest, earliest galaxies to today's grand spirals and ellipticals, helping us to understand how galaxies assemble over billions of years.

Read More

Birth of Stars & Protoplanetary Systems

JWST will be able to see right through and into massive clouds of dust that are opaque to visible-light observatories like Hubble, where stars and planetary systems are being born.

Read More

Planets & Origins of Life

JWST will tell us more about the atmospheres of extrasolar planets, and perhaps even find the building blocks of life elsewhere in the universe. In addition to other planetary systems, JWST will also study objects within our own Solar System.

Read More
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What ALMA studies need to be done **NOW** in preparation?

Aravena et al. (2016)

Dunlop et al. (2016)
Obscuration to Reionization:
Blank-Field 2mm Deep Survey in COSMOS

Our large program, 230 arcmin² to 80μJy RMS at 2mm (band 4)
Goal: Constrain 40<SFR<1000 M_☉/yr galaxies beyond z~5

Typical UV-selected galaxy at z=5.15 (Capak et al. 2015)
SFR $\sim 6$ M_☉yr$^{-1}$
Uncovered in deep optical imaging over <1 sq deg areas. Fairly common.

Extremely luminous FLS3 at z=6.34 (Riechers et al. 2013)
SFR $\sim 3000$ M_☉yr$^{-1}$
Discovered via very wide-field (>100 sq deg), shallow Herschel surveys. Extremely rare.

These galaxies become the earliest massive galaxies.
Yet they are unconstrained!
Obscuration to Reionization: A Blank-Field 2mm Deep Survey in COSMOS

63 hour large program, 230 arcmin$^2$ to 80uJy RMS at 2mm (band 4)

Goal: Constrain 40<$\text{SFR}$<1000 $M_\odot$/yr galaxies beyond $z$~5

Observational strategy requires wider-field, shallower blank field survey than existing deep field programs.

JWST will constrain metallicity, dynamics, of first starburst galaxies (if we find them).
Synergies

How can ALMA steer the extragalactic science goals for next generation facilities?

Summary

great progress with:
- lensed samples
- dust continuum
- small samples of “normal” high-z galaxies

what to do next:
- make CO spectral scans efficient for the unlensed
- embark on several, diverse large programs to make real impact at $z>3$: dust continuum, blank fields (confirm sources that have evaded identification for years, identify sample of unlensed DSFGs beyond $z>5$, building blocks of first galaxies, map molecular gas out to reionization)

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