Dust continuum and [CII] line emission from ASPECS: The ALMA Spectroscopic Survey in the Hubble UDF

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State of the art: ALMA continuum millimeter deep fields

SXDF-UDS-CANDELS 1.1-mm survey: 1.5-arcmin$^2$ map down to 1σ $\sim$50 µJy per 0.5" beam (Kohno+16; Hatsukade+16; Yamaguchi+16)

Hubble UDF 1.3-mm survey: 4.5-arcmin$^2$ map down to 1σ $\sim$35 µJy per 0.7" beam (Dunlop+16).
The ASPECS different strategy:

- Spectral scan over the full bands 3 and 6 in a 1 arcmin² region in the UDF/XDF field.
- Frequency coverage covers CO/[CI] at 0<z<6 and and [CII] line at 6<z<8.
- Obtain ultra-deep continuum at 1.2-mm by collapsing the 212-272 GHz cube.
ASPECS 1.2-mm continuum:

- Nine sources detected at 1.2-mm down to S/N>3.5 (1 σ=13 µJy) within 1 arcmin² area, with a resolution of 1-2"
- One source detected at 3-mm within 1 arcmin² area, with a resolution of ~3"

Aravena et al. (2016a)
ASPECS 1.2-mm continuum: Dusty star forming galaxies (DSFGs)

The depth of HST images allow us to find counterparts for 7/9 mm sources.
Continuum detected galaxies lie in the "main sequence" (no “starbursts”)
- Galaxies redshifts between z=1.0-3.0
- Redshift distribution implies a median redshift of $z_{\text{med}}=1.7+/-0.4$ (brighter samples indicate at $z_{\text{med}}\sim2.0-3.0$)
- Stacking analysis suggest underlying millimeter population is dominated by galaxies at $z=1-2$, and typical stellar masses $>10^{9.5} \, M_{\odot}$ and SFR $> 10 \, M_{\odot} \, \text{yr}^{-1}$.

Aravena et al. (2016a)
ASPECS 1.2-mm continuum: the Extragalactic Background Light (EBL)

Number counts a factor of 2 lower than other studies. ASPECS is able to resolve out to 80% of the EBL at 1mm.
There appear to be systematic differences between different estimates of the gas masses compared the CO derived H2 masses.
Stacking analysis of z=2-10 galaxies to measure average $L_{IR}$ and specifically the infrared excess $IRX = \log(L_{IR}/L_{UV})$ as a function of stellar mass and UV slope ($\beta$).

Constraints on the shape of low-mass galaxies SEDs. Our results suggest that faint high-z galaxies show less dust emission than any local template.

Bouwens et al. (2016)
Only galaxies with $M^* > 10^{9.75} \, M_\odot$ tend to have $>50\%$ of their energy output at FIR. Results consistent with an SMC IRX-\(\beta\) relation for high mass galaxies, but imply lower IRX for low mass galaxies.

Bouwens et al. (2016)
ASPECS 1.2-mm continuum: Dust obscuration properties of faint galaxies at $z>2$

Bouwens et al. (2016)
ASPECS [CII] line search at z=6-8

Specific search for [CII] line emission based on:

**Blind candidates:** Significant 1-mm line peaks (S/N>5.3) associated to optically faint sources at z\textsubscript{phot}=5.5-8.5 or without counterparts at all. Result: 2.

**Optically-selected candidates:** 1-mm line peaks (S/N>4.5) associated to optical dropouts with z\textsubscript{phot}=5.5-8.5. Result: 12.

Limiting luminosities for [CII] and high-J CO lines in the redshift range 6-8

Aravena et al. (2016b)
ASPECS [CII] line search at $z=6-8$: Blind candidates

Candidate [CII] line emission in the two "blind" candidates. Aravena et al. (2016b)

Multi-wavelength postage stamps around the candidate [CII] line peak. No obvious counterpart is seen in either case.
ASPECS [CII] line search at z=6-8: optical dropout candidates

Aravena et al. (2016b)
ASPECS [CII] line search at $z=6-8$: optical dropout candidates

Aravena et al. (2016b)
ASPECS [CII] line search at z=6-8: possible blind detection at z=6.3?

Aravena et al. (2016b)
ASPECS [CII] line search at z=6-8: possible blind detection at z=6.3?

Aravena et al. (2016b)
ASPECS [CII] line search at \(z=6-8\): SFRs and constraints on [CII] number counts

Most source candidates have too low SFRs for their candidate [CII] line emission compared to previous high-z detections. Even if one of these sources is real, it already contradicts with models of galaxy formation.
ASPECS **very deep**: ultra deep 1-mm pointing and scan in the Hubble UDF

**Preliminary continuum image:**

Continuum image reach down to $\sim 4-5\mu$Jy rms (current image tapered to 1’’): Few sources detected in the field by going 2-3x deeper.

Full spectral scan in band-6 will be able to confirm/reject a few [CII] line candidates

CO line search to complement and confirm line candidates
ASPECS Large Program:

- ASPECS LP covers 5x larger area at similar depth than our pilot program. Capitalization on results and many unexplored areas.
- We expect to detect ~50 galaxies at >3.5s in 1-mm continuum
- Increased sensitivity down to 9 \( \mu \)Jy in the pilot area
- Continuum stacking in ~10000 SF galaxies
- Continuum stacking in ~1000 LBGs at z=2-6 (IRX vs \( \beta \))
- Access to [CII] search + continuum in 60 dropouts at z=6-8
- Invisible galaxies?
- Etc…
The ASPECS pilot program results and science areas are summarized in our 7 papers (ApJ in press):

- Survey description, observing strategy and blind molecular line search (Walter et al. 2016)
- Molecular gas and properties of individual galaxies (Decarli et al. 2016a)
- CO luminosity function and cosmic density of molecular gas (Decarli et al. 2016b)
- Dust continuum emission and properties of mm-selected galaxies (Aravena et al. 2016a)
- Search for [CII] line emission in z=6-8 galaxy candidates (Aravena et al. 2016b)
- Constraints on the dust emission in LBGs at z=2-10 (Bouwens et al. 2016)
- Implications for CO intensity mapping and CMB spectral distortions (Carilli et al. 2016)