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A Multi wavelength View on Massive Star Forming Companion Galaxies to High-Redshift Quasars

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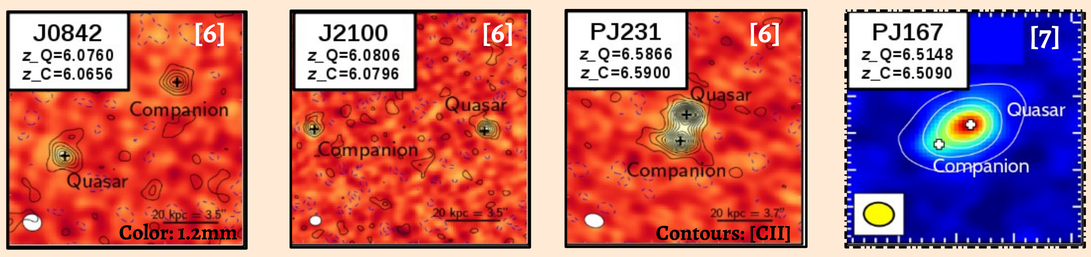
OBJECTIVE High-redshift quasars, $z > 6$, i.e. < 1 Gyr from the Big Bang, are predicted to be found in the high-density peaks of the dark matter distribution, surrounded by overdensities of galaxies[1,2]. UV-based observational studies have reported inconclusive evidence so far[3,4,5]. Previous ALMA observations of the cool gas and dust in a sample of quasars unveiled the presence of additional [CII]- and far infrared (FIR)-bright companion galaxies (L_{IR} ~ few 10^{11} Lsun, $L_{[CII]}$ ~ few 10^{9} Lsun), at a mere projected distance of < 60 kpc and velocity distance of < 450 km/s[6,7]. These galaxies are probably undergoing a gravitational interaction with the quasars, and pin-point highly rich regions of the early universe.

Here, we aim at characterizing the spectral energy distribution (SED) of four galaxies adjacent to four $6 < z < 6.6$ quasars, through newly acquired, sensitive, multi-wavelength imaging follow-up observations.

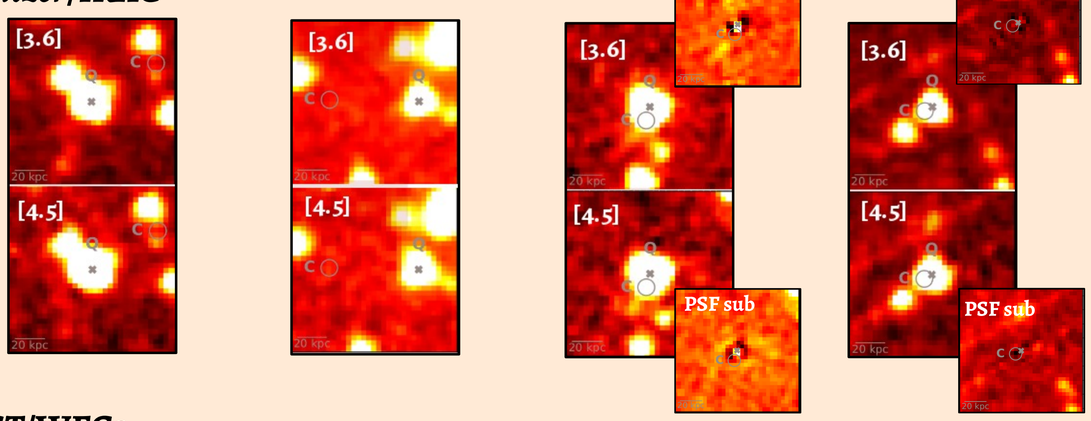
DATASET

We use archival ALMA Band 6 observations of the dust continuum and [CII] emission line[6,7], new dedicated *Spitzer*/IRAC [3.6] and [4.5] deep imaging, probing the bulk of the galactic stellar population, and *HST*/WFC3 imaging in the F140W filter, sampling the emission from young stars.

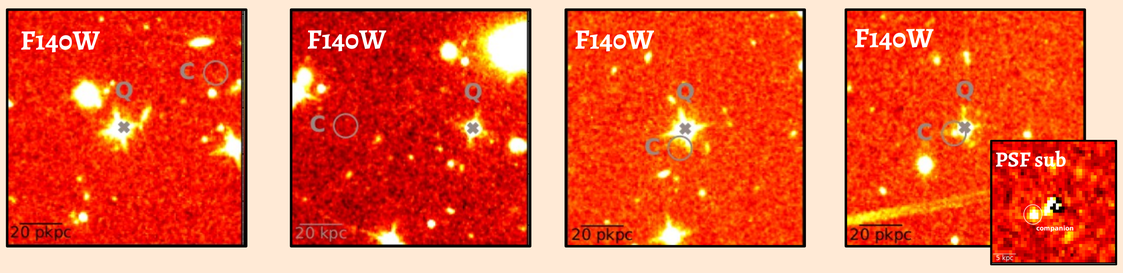
ALMA



Spitzer/IRAC



HST/WFC3



The companion galaxies of J0842, PJ231 and J2100 are not detected at S/N > 3 in the *HST*/WFC3 and *Spitzer*/IRAC images.
The galaxy adjacent to PJ167 is not detected in the *Spitzer*/IRAC data, but it shows a detection in the *HST*/WFC3 with magnitude F140W = 25.48 ± 0.17.

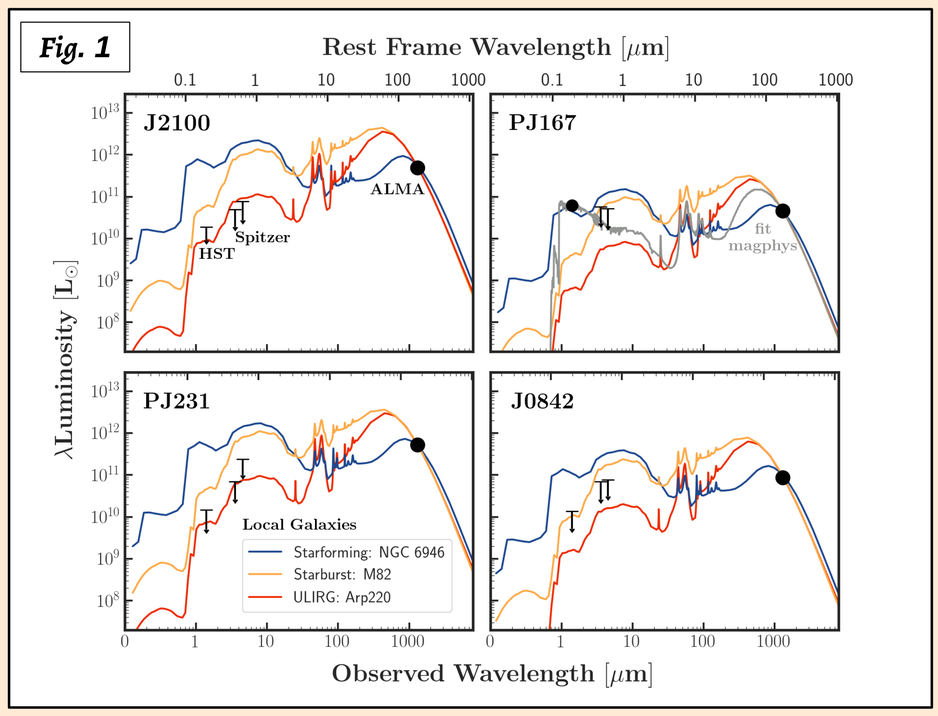
SED AND GALACTIC PROPERTIES MODELING

We compare the SEDs of the companion galaxies to those of representative local star-forming/star-bursting/ultraluminous infrared (ULIRG) galaxies [*Fig 1*].
We also fit the SED of the companion to PJ167 with the software MAGPHYS-highz[12], from which we derive its stellar mass [*Fig 1, upper right*].

We derive the properties of the companion galaxies:

- **Obscured Star Formation Rate**, i.e. the stellar emission reprocessed by dust (**SFR_{IR}**), sampled with ALMA. We convert the total infrared luminosity (integrated within 3-1000 μm) to a SFR following [5].
- **Unobscured Star Formation Rate**, i.e. the emission of 10-200 Myr old stars (**SFR_{UV}**), sampled with *HST*/WFC3. We convert the monochromatic ultraviolet luminosity to a SFR using the scaling relation from [5].
- **Stellar Mass** limits on the companions to J0842, PJ231 and J2100, using the dynamical and gass masses derived from the ALMA measurements from [6].

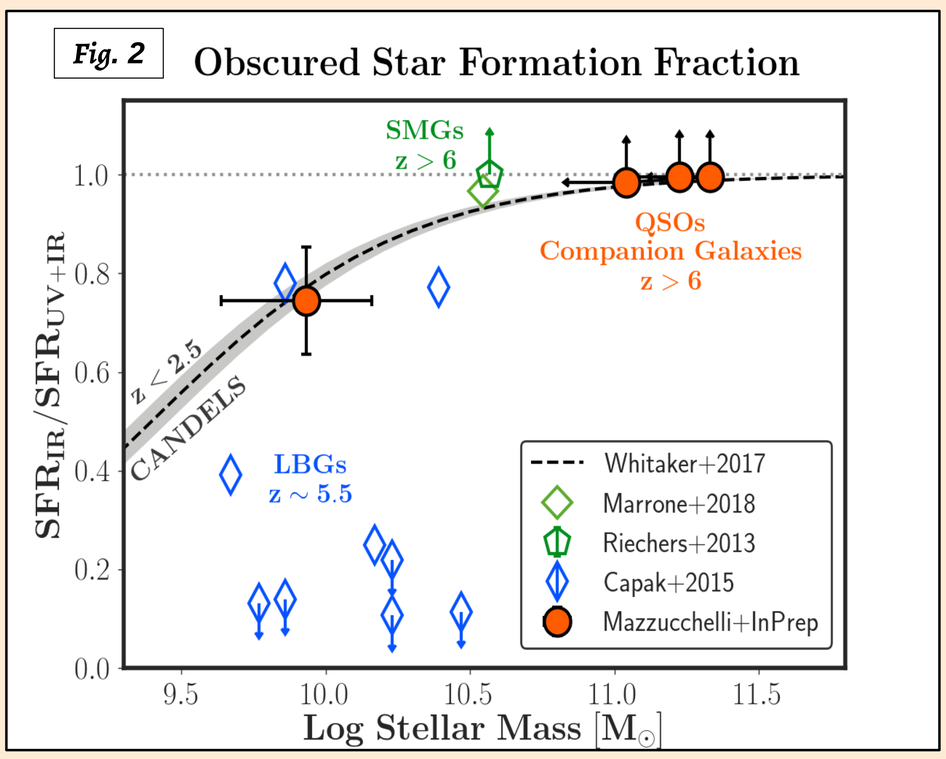
Fig. 1



TAKE HOME 1 : The SEDs of three companion galaxies to quasars at z > 6 are consistent with an Arp 220-, i.e. ULIRG-, like template, vestigial of a recent massive gas-rich merger.

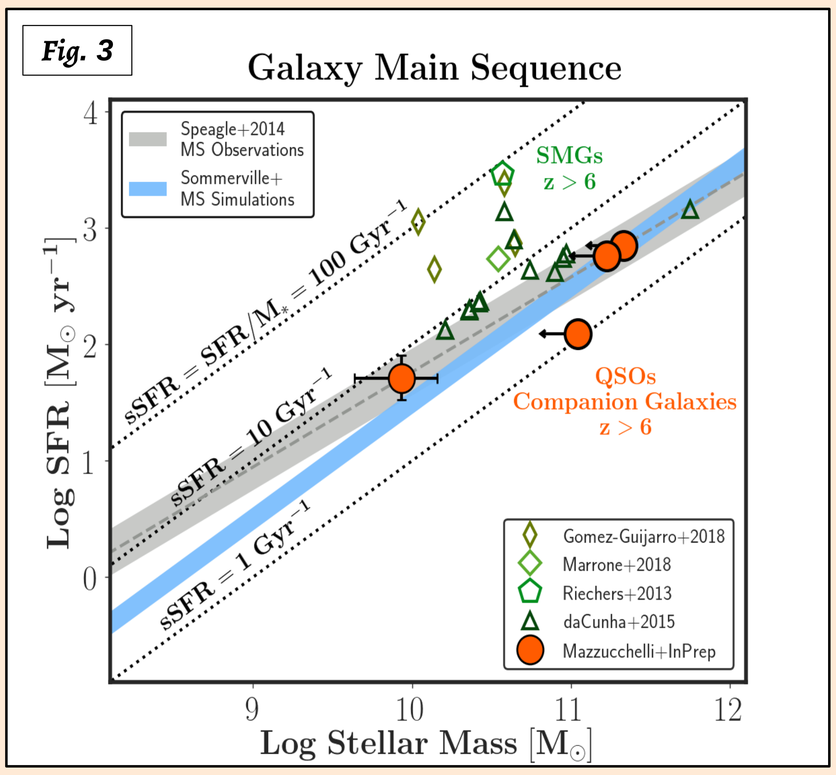
CONTEXT OF THE HIGH-REDSHIFT GALAXIES POPULATION

Fig. 2



TAKE HOME 2 : Three companion galaxies to $z > 6$ quasars present an obscured SFR (~ 100-700 Msun/yr) > 100 x unobscured SFR (2-3 Msun/yr).
The galaxy adjacent to PJ167 presents a lower SFR obscured fraction of ~0.7.

Fig. 3



TAKE HOME 3 : The galaxies adjacent to high-redshift quasars are consistent with being on the main sequence of starforming galaxies. Future observations with, e.g. JWST, will be fundamental in characterizing these sources and their stellar masses.

References:

[1] Springel+2005, Nature,435,629 ; [2] Overzier+2009, MNRAS,394,577 ; [3] Morselli+2014, A&A,568,1 ; [4] Mazzucchelli+2017a, ApJ,849,91 ; [5] Goto+2017, MNRAS,470,117 ; [6] Decarli+2017, Nature, 545, 457 ; [7] Willott+2017, ApJ, 850, 108; [8] Whitaker+2017, ApJ,850,308 ; [9] Marrone+2018, Nature,553,51; [10] Riechers+2013, Nature,496,329 ; [11] Capak+2015, Nature,522,455 ; [12] Gomez-Guijarro+2018, ApJ,856,121 ; [12] da Cunha+2015, ApJ,806,110