Resolving distant quasar host galaxies with high angular resolution techniques

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We present the latest results from an Integral Field Spectroscopy OSIRIS-LGS survey to resolve and study high-redshift (z = 1.4 - 2.5) radio-loud quasar host galaxies. Keck Adaptive Optics (AO) with OSIRIS provides the necessary resolution and contrast to remove the bright-unresolved quasar emission to study the underlying faint host galaxy with unprecedented sensitivity. Thus far, our radio-loud sample consists of eight high-redshift quasar hosts with ionized gas emission resolved at sub-kiloparsec scales, yielding essential constraints on the galaxies dynamics, morphologies, star formation rates, metallicities, and nebular emission diagnostics. We combine OSIRIS and AO observations with multi-wavelength data sets from Atacama Large Millimeter/submillimeter Array, Hubble Space Telescope, and Very Large Array to better understand the multiple phases of the ISM and stellar population properties of the hosts. These quasar hosts show evidence for both concurrent star formation and extended quasar narrow line emission over 1 to 20 kpc. Powerful outflows are observed along the path of the radio jets and lobes, with a suppression of star formation by a factor of 10 in some sources compared to other regions of the host galaxies.

Sample:

Redshift: 1.39 < z < 2.5
Bolometric luminosities: >10^{47}erg/s
Radio loud compact steep spectrum (CSS) quasars
Sources randomly selected based on tip/tilt star availability for LGS-AO: R [mag]< 17.0 within 45"
or quasars with R [mag] <18.0 for on axis corrections.

Multi-wavelength data

OSIRIS LGS-AO Observations of Extended Nebular Emission Lines

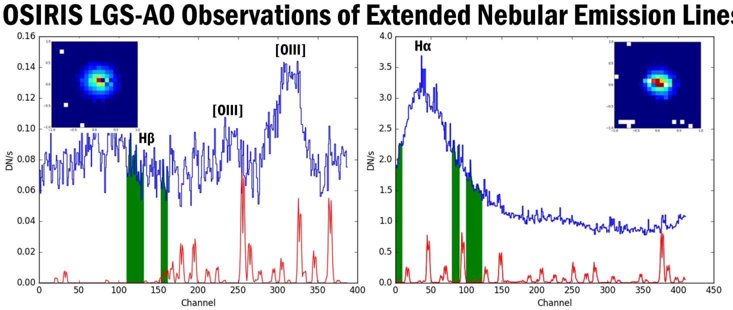

Figure 1: J(left) and H(right) band spectra of a z=1.439 QSO. Broad emission lines such as Hα and Hβ arise from the unresolved broad line region and are used to generate a PSF for subtracting out QSO emission to search for extended nebular emission from the host galaxy. Here we present the wavelength regions from which the PSF is usually constructed (highlighted in green), a 2D image of the PSF is presented in the upper corner. We select channels that maximize the SNR of the PSF that do not fall in spectral regions where narrow-line emission is expected from the quasar/host galaxy, and do not overlap with strong OH emission lines or telluric absorption regions, and are as close as possible to the nebular emission line that is being analyzed. After the PSF image is constructed it is removed from all the spectral channels in our data cube, to reveal extended emission. We observe the nebular emission lines Hβ, [OIII], Hα, [NII], and [SII] to characterize the star formation rates and distribution, excitation diagnostics, morphologies, and kinematics of the ionized ISM.

ALMA Molecular ISM observations through ^{12}CO

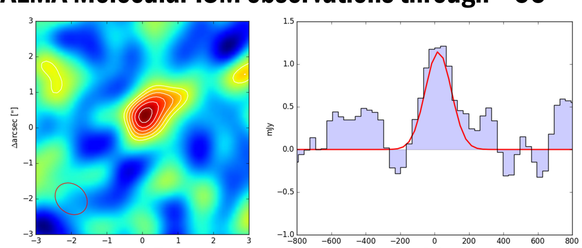

Figure 2: ALMA band 4 CO 3-2 observations of a z=1.439 QSO. By observing the distribution and dynamics of molecular emission and relating them to outflow and star forming regions detected in ionized emission we can constrain the depletion time scales of the molecular ISM due to star-formation and/or quasar feedback. Left: two dimensional map of the CO 3-2 line created by summing the data cube over channels from -200 km/s to +200 km/s. White contours stretch from +5σ to 2σ at intervals of 0.5σ . Right is the spectrum of the CO 3-2 line created by spatially integrating over the spaxels with 3σ-5σ emission. A Gaussian fit to the emission line is highlighted in red. On the right, the lower left circle represents the synthesized beam of 0.98" by 0.80".

Stellar Continuum Hubble Space Telescope Observations:

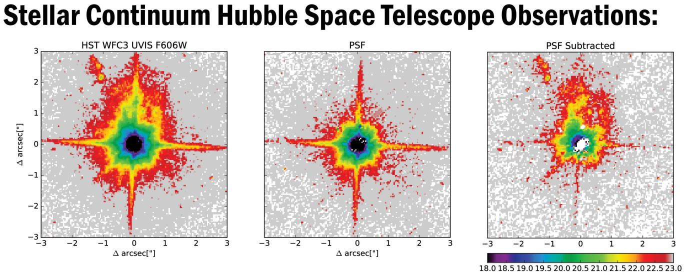

Figure 3: HST WFC3 UVIS observation trace the near-UV stellar continuum for this z=1.43 QSO. Our multi frequency survey attempts to link resolved stellar structure of QSO hosts' from broadband HST observations to isolated shocked outflow and star forming regions, therefore linking feedback from AGN to star formation efficiency of the hot and cold ISM at z>1. The left image shows the QSO with an extended surface brightness, middle is our re-constructed PSF (using both an observed star in the field coupled with Tiny Tim), and right is the PSF subtracted image showing extended structure spanning several arcseconds.

Results:

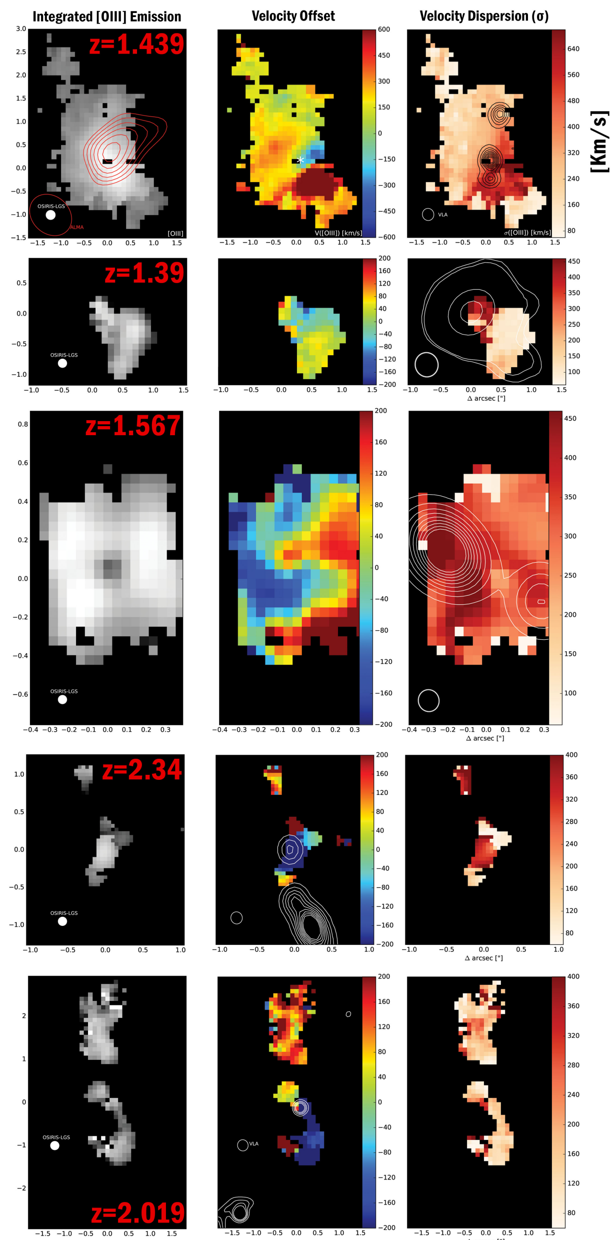

Figure 3: PSF subtracted [OIII] 500.7nm maps of five sources in our sample. On the left are line-integrated intensity maps, in the middle are velocity offset maps relative to the redshift of the broad line region, on the right velocity dispersion maps. Contours represent VLA radio maps of the synchrotron emission produced by the quasar jets/lobes. For the top four sources; regions with the highest velocity dispersion/velocity offset correspond to either the path of the quasar jet or the location of radio lobes. Generally, these regions show evidence for suppression of star formation rate compared to other parts of the host galaxy, ranging from a factor of 5-10 or as large as 15 in the z=1.439 galaxy. For the z=1.439 and 1.567 quasars these jets are driving bi-conical outflows through the galaxy while for the z=1.39 and z=2.34 only single blue/redshift outflow region are present.