The Galaxy Environments of Supermassive Black Holes at $z \approx 2.7$

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**PROJECT**

- We are constraining properties of the environments of hyperluminous QSOs:
  - Host halo mass
  - Total dynamical mass in surrounding region
  - Bias with respect to galaxy population
- Our constraints are based on detailed studies of the 3D distribution of the galaxies surrounding these QSOs (i.e. their clustering properties and peculiar velocities)
- QSOs may be fairly average galaxies caught at a special time in an otherwise normal process of evolution
- Understanding QSO environments informs us of the lifetimes and duty cycles of active phases in supermassive black holes

**DATA**

- 15 fields centered on hyperluminous QSOs at $z = 2.7$
  - 1522 galaxies within 3.4' of QSO lines of sight with spectroscopic redshifts $1.4 < z < 3.5$
  - Low-resolution (5-10 Å) rest-frame UV spectra taken with LRIS-B (Keck), $\sigma_v = 0.002 = 120$ km/s
  - QSO redshifts from rest-frame optical spectra taken with NIRSPEC (Keck) and TripleSpec (Palomar 2000), $\sigma_v = 0.0005 = 30$ km/s
- Halo catalogues from the Millennium Simulation ($z = 2.62$) were used to determine the mass scale of halos with similar clustering characteristics to our data

**RESULTS**

- Hyperluminous QSOs are associated with significant overdensities in the distribution of surrounding galaxies
  - The projected scale (R $\approx 500$ h$^{-1}$ comoving kpc) and velocity scale ($\sigma_v = 500$ km/s) of these overdensities imply (via virial arguments) a dynamical mass scale $M_{\text{dyn}} = 10^{13} M_{\odot}$ for the overdensities, consistent with a proto-group environment
  - The galaxy autocorrelation function, when compared with results from halo catalogs, suggests our galaxies have halo masses $M_{\text{halo}} \approx 10^{12.0} M_{\odot}$, in agreement with previous measurements
  - The galaxy-QSO cross-correlation function suggests that these hyperluminous QSOs inhabit halos $M_{\text{QSO}} \approx 10^{12.7} M_{\odot}$, only ~5x more massive than the typical galaxy in our sample

**FUTURE WORK**

- We are finishing a survey for narrow-band Lyα-selected objects in 8 of the hyperluminous QSO fields, which may exhibit fluorescence
- Results reveal the Mpc-scale distribution of gas around bright QSOs and the effect of QSOs on this environment

**Fig. 1:** Autocorrelation function for galaxies in our sample (black points) and their cross-correlation function with the nearby QSOs (red points). The galaxy autocorrelation is consistent with the fit to $10^{12.5} M_{\odot}$ halos from the Millennium simulation (black line), and the galaxy-QSO cross-correlation matches the fit to the cross-correlation between simulated $10^{12.5}$ and $10^{12.7} M_{\odot}$ halos (red line).

**Fig. 2:** Line-of-sight distribution of galaxies in units of velocity with respect to their nearby QSOs. There is a large overdensity at the location of the QSOs with a velocity dispersion $\sigma_v = 430$ km/s (corrected for redshift errors), which we attribute to peculiar velocities.

**Fig. 3:** LRIS G-band image of the field surrounding the QSO Q1549+1919. The red circles correspond to galaxies with spectroscopic redshifts suggesting they are associated with the QSO, while blue (green) circles denote galaxies in the foreground (background) of the QSO.

**Fig. 4:** For each projected circular annulus, the fraction of galaxies within that annulus that are also within 1000 km/s of the QSO (black). The red line denotes the fraction of all galaxies within this velocity range. The overdensity of galaxies is localized to a transverse scale $R = 500$ h$^{-1}$ comoving kpc.