Gas and Star Formation in the Quasar Host Galaxies at z~6

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• Gunn-Peterson absorption: first generation of SMBHs and galaxies close to the end of cosmic reionisation;
• Black hole masses on order of a few $10^8$ to $10^{10}$ $M_{\odot}$;
• Significant SMBH and galaxy evolution within 1 Gyr of the Big Bang;
• Best sample to study the early evolution of the first SMBH-galaxy system.
Millimeter continuum survey: dust and star formation in the earliest quasar host galaxies

- Strong dust Continuum emission has been detected in the host galaxies of quasars known at z~6.
  - Detection rate: ~30% of the optically luminous sample at sub-mJy sensitivity (Priddey et al. 2003; Robson et al. 2004; Wang et al. 2007, 2008, 2011). Much lower in less luminous sample (e.g., Omont et al. 2013);
- Detections: FIR luminosities of a few $10^{12}$ to $10^{13}$ $L_{\odot}$;
- SFR: a few $10^2$ to $10^3$ $M_{\odot}$/yr.
- \([\text{C II}]\) with ALMA, distribution of star formation, dynamics of atomic gas;
- CO (6-5) with the PdBI;
- CO(2-1) with the VLA;
- Spatial distribution, mass, dynamics of the molecular gas
Millimeter observations of the most massive quasar SDSS J0100+2802

- Line detection and ISM excitation; NOEMA, JVLA
Millimeter observations of the most massive quasar SDSS J0100+2802

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Wang et al. 2016 in press
Spatially resolved ISM and star formation

[C II] ALMA, Wang et al. 2013

CO (2-1), JVLA, Shao et al. 2016, in prep.
Observations with ALMA

- ALMA cycle 1 observations: 0.2″~0.3″ resolution [C II] imaging of three millimeter bright z~6 quasars, Shao et al. 2016 in prep.;

- ALMA cycle 3 observations: High-J CO transitions and fine structure lines to study the physical conditions of the ISM from the most millimeter luminous quasar at z~6;
Rotating gas in the quasar host galaxies

Shao et al. 2016 in prep.
Very turbulent [C II] emitting gas in the host galaxy of one quasar
ALMA [C II] imaging of z~6 quasars

- We obtained 0.2”~0.3” resolution imaging of the [C II] line from three of mm-bright z~6 quasars;
- Line velocity maps of two of them indicating rotating gas kinematics, and we obtained rotation curve for the brightest object;
- Very turbulent gas seen in the third object, AGN feed back?
Host galaxy dynamical masses from the [C II] images;
The SMBH/bulge mass ratio of the most massive objects is about an order of magnitude higher compared to the local trend, i.e., Kormendy & Ho (2013);
The objects with lower SMBH masses are more close to the local relation (Willott et al. 2015).

Wang et al. 2016, in press
Summary

- Quasars at the highest redshift provide the best sample to study SMBH-galaxy co-evolution at the earliest epoch;
- Detections of CO and [C II] lines, gas distribution and physical condition of the ISM;
- ALMA resolve the star forming ISM on 1~2 kpc scales;
  - Constrain the distribution of star formation;
  - Constrain the gas kinematics: rotating gas disk, turbulent clumps;
- SMBH-galaxy relationship in the earliest SMBH-galaxy systems: the system with the most massive SMBHs are likely to be above the local trend.