

Gas and Star Formation in the Quasar Host Galaxies at $z \sim 6$

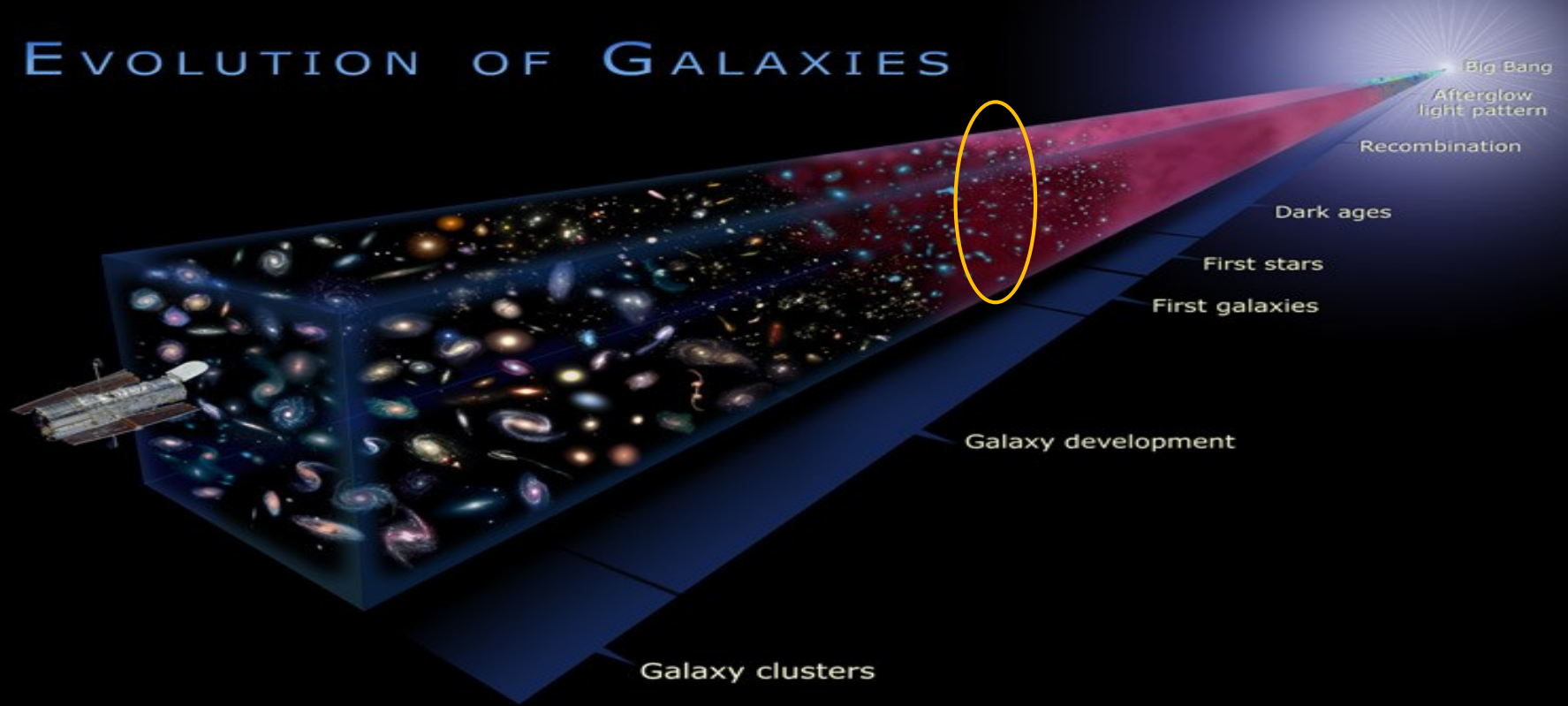
Ran Wang

KIAA, PKU,

06. 30. 2016, MPIA, Heidelberg

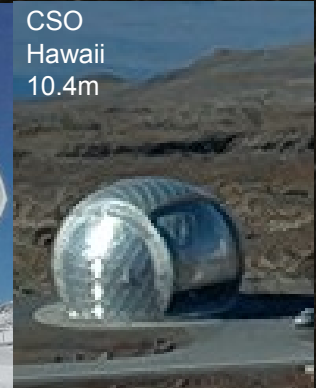
Collaborators : Carilli, C. (NRAO); Walter, F. (MPIfA); Fan, X. (Steward); Wagg, J. (NRAO); Neri, R. (IRAM); Bertoldi, F. (University of Bonn); Riechers, D. (Caltech); Omont, A. (IAP); Strauss, M. (Princeton); Cox, P. (IRAM); Menten, K. (MPIfR); Wu, X. (KIAA-PKU); Jiang, L. (KIAA-PKU); Shao, Y. (KIAA-PKU)

EVOLUTION OF GALAXIES



- 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 $10^{10} M_{\text{sun}}$;
- 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 $z \sim 6$.
 - Detection rate : $\sim 30\%$ 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 $10^{13} L_{\text{sun}}$;
- SFR : a few 10^2 to $10^3 M_{\text{sun}}/\text{yr}$.

JVLA



PdBI(NOEMA)



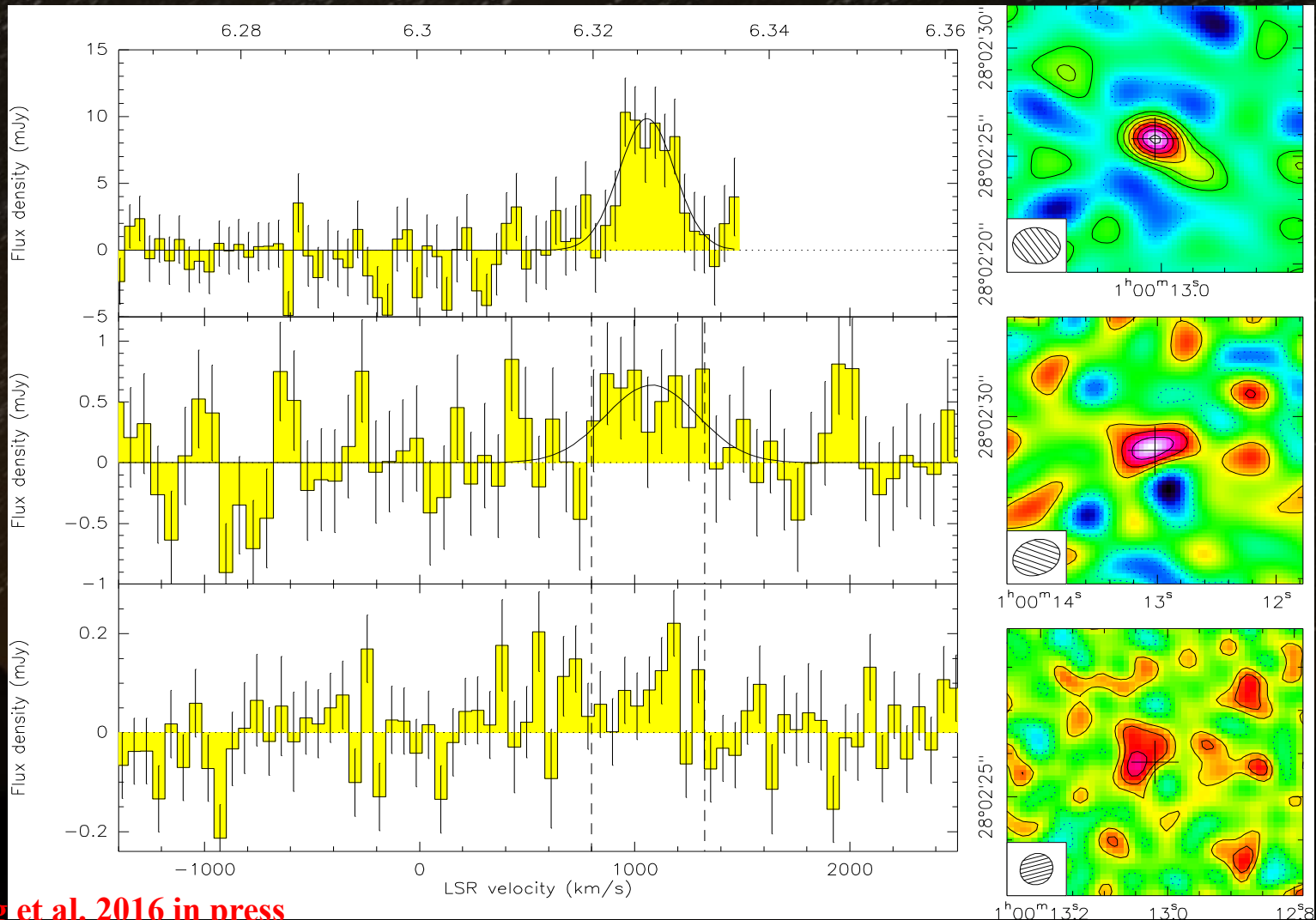
ALMA



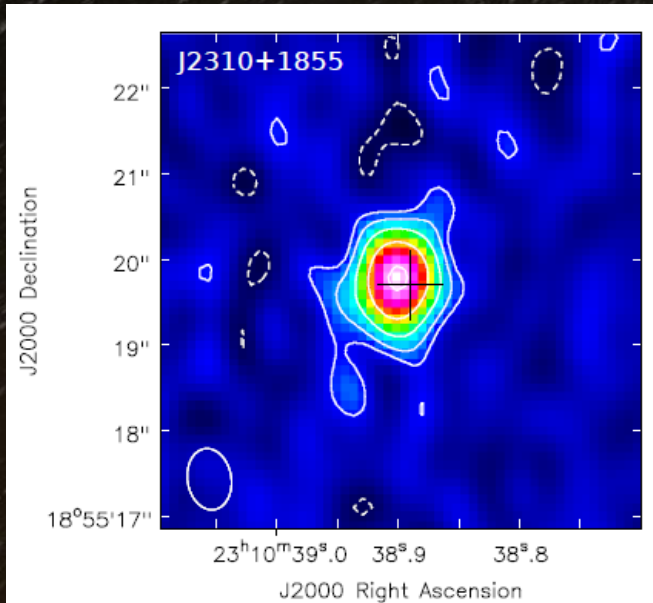
- [C II] with ALMA, distribution of star formation, dynamics of atomic gas ;
- CO (6-5) with the PdBI;
- CO(2-1) with the VLA;
- Spatial distribution, mass, dynamics of the molecular gas

Millimeter observations of the most massive quasar SDSS J0100+2802

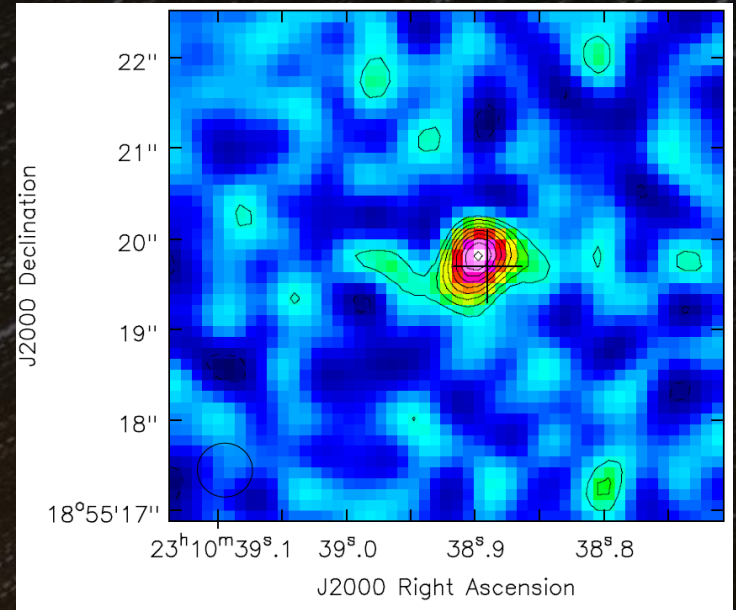
- Line detection and ISM excitation ; NOEMA, JVLA



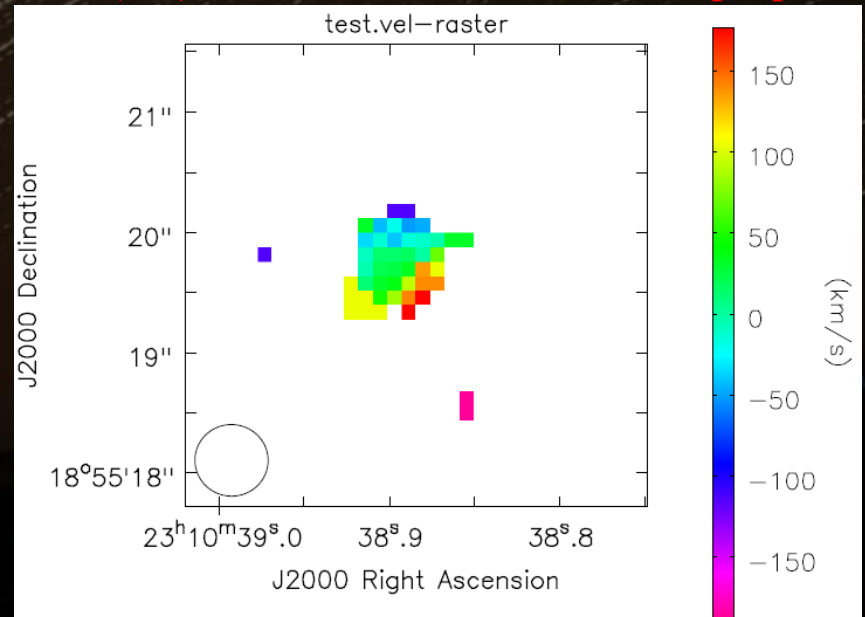
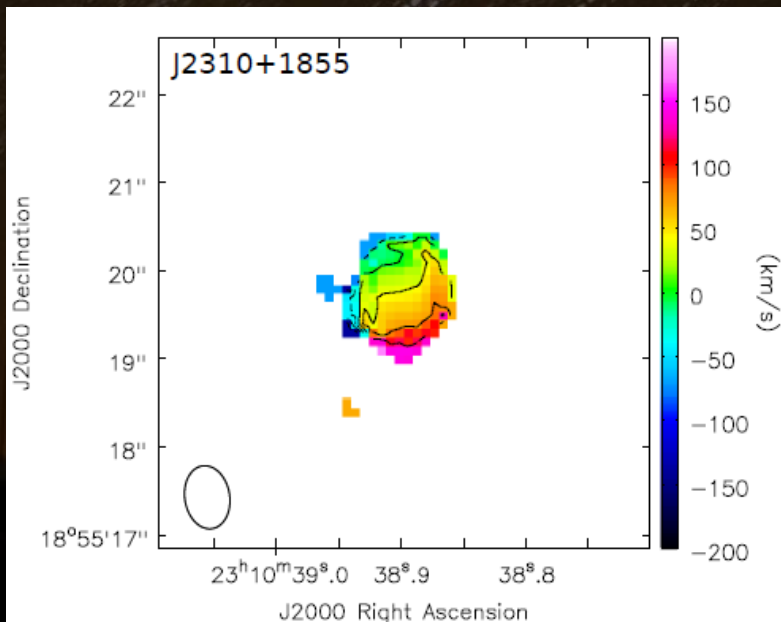
Spatially resolved ISM and star formation



[C II] ALMA, Wang et al. 2013



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

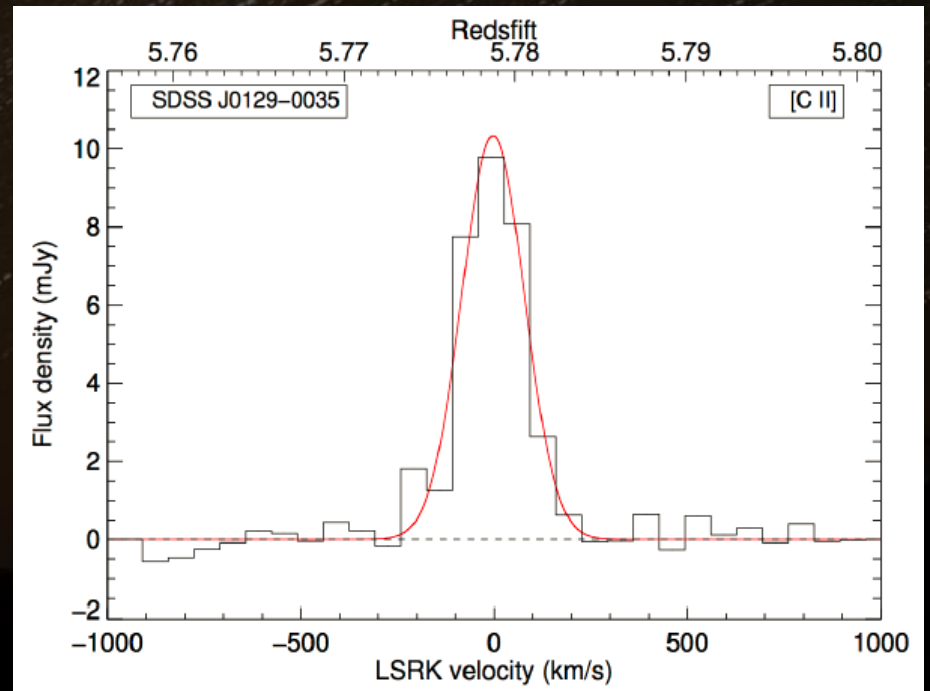
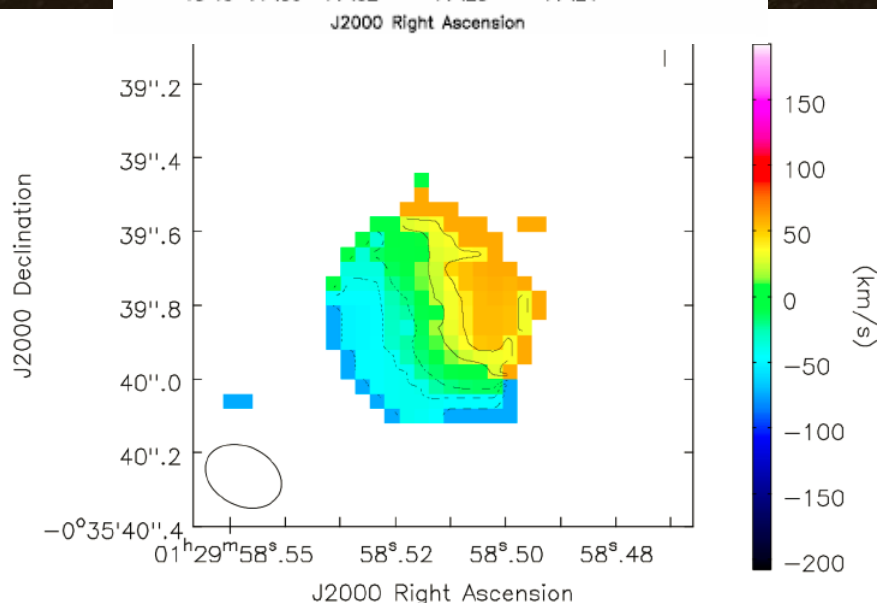
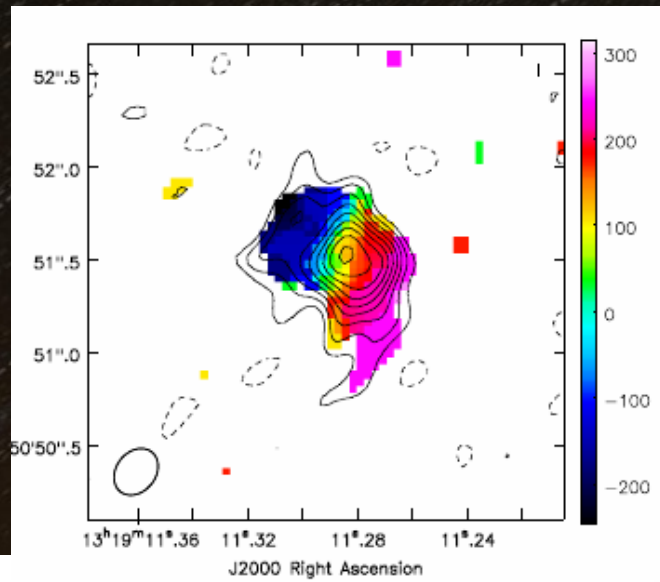


Observations with ALMA



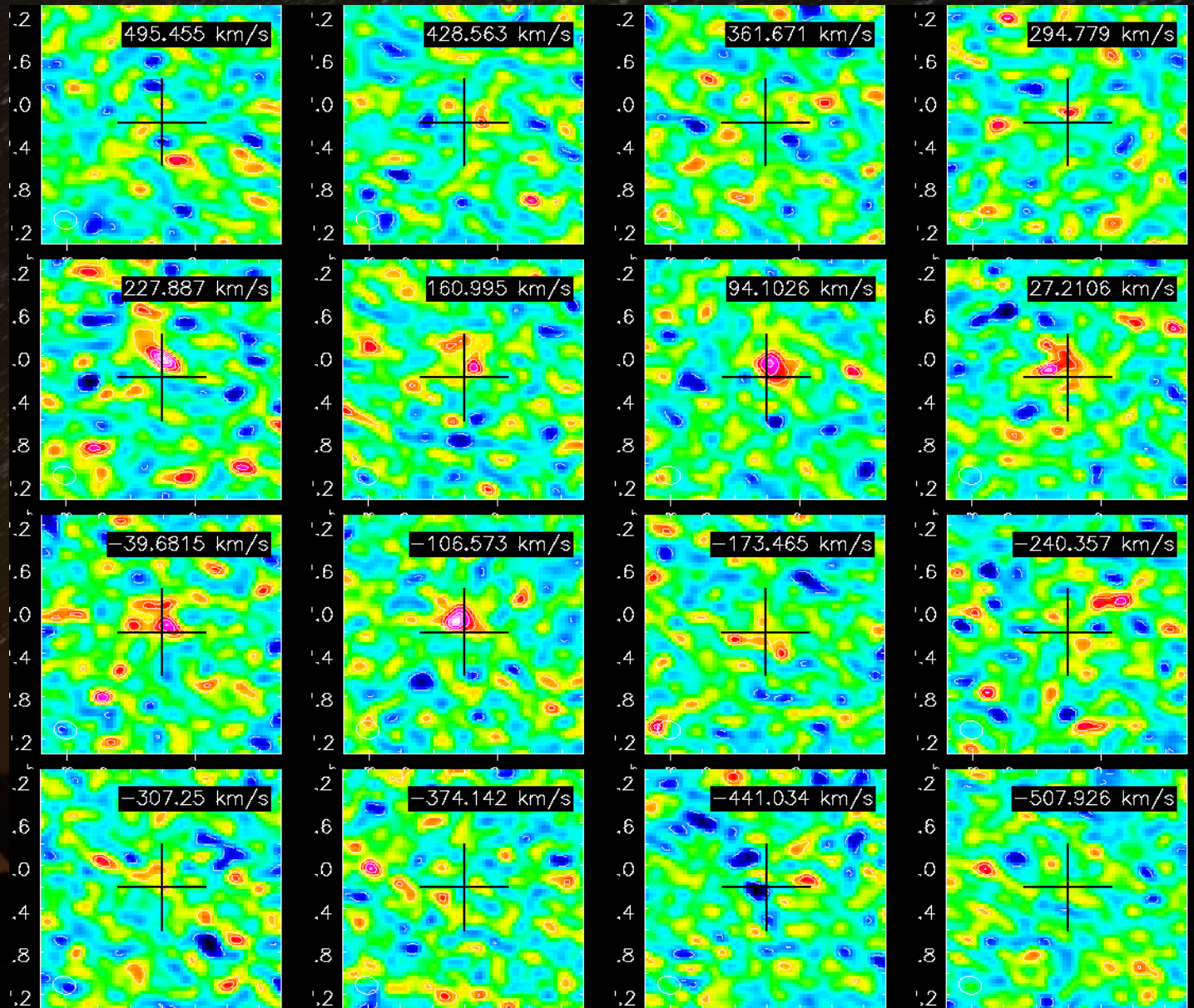
- ALMA cycle 1 observations : $0.2'' \sim 0.3''$ resolution [C II] imaging of three millimeter bright $z \sim 6$ quasars, Shao et al. 2016 in prep.;
- ALMA cycle 3 observations : High-J CO transitions and fine structure lines to study the physical conditions of the ISM from the most millimeter luminous quasar at $z \sim 6$;

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

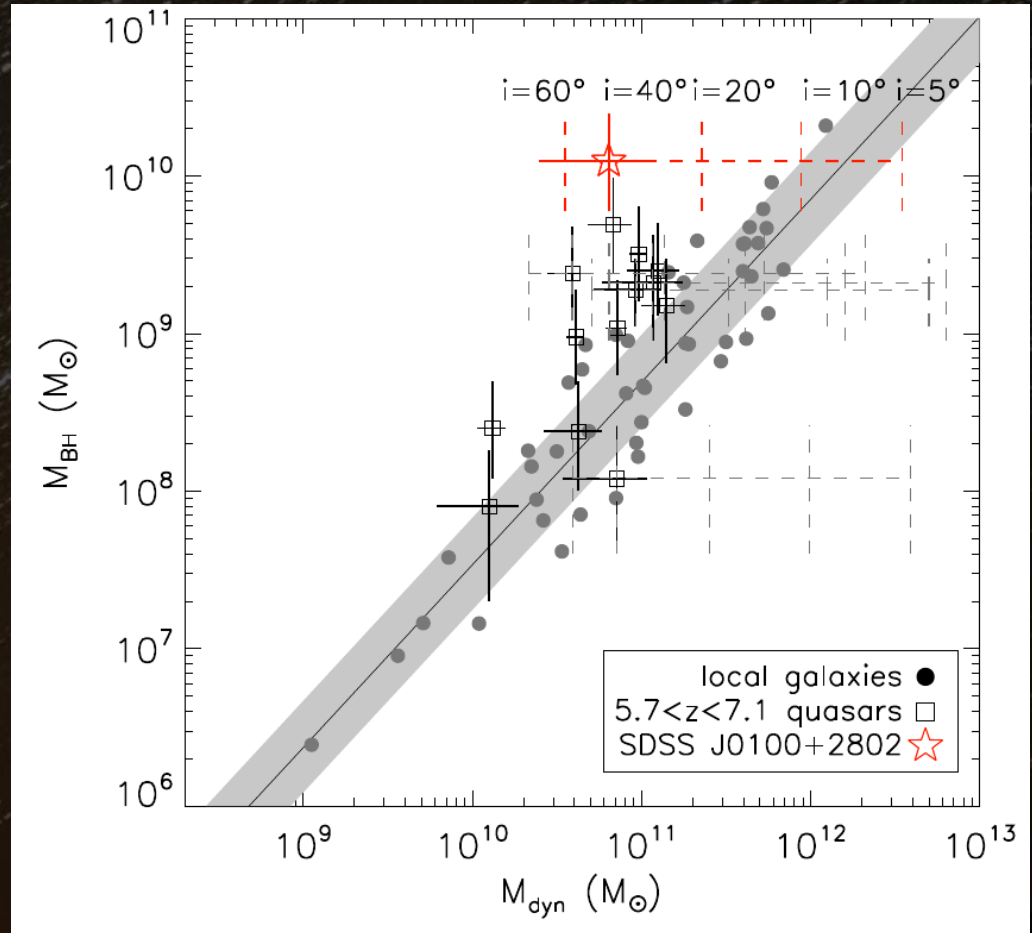


ALMA [C II] imaging of $z \sim 6$ quasars

- We obtained $0.2'' \sim 0.3''$ resolution imaging of the [C II] line from three of mm-bright $z \sim 6$ 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 feedback ?

SMBH-galaxy co-evolution

- 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.