# High-redshift quasars and the epoch of reionization

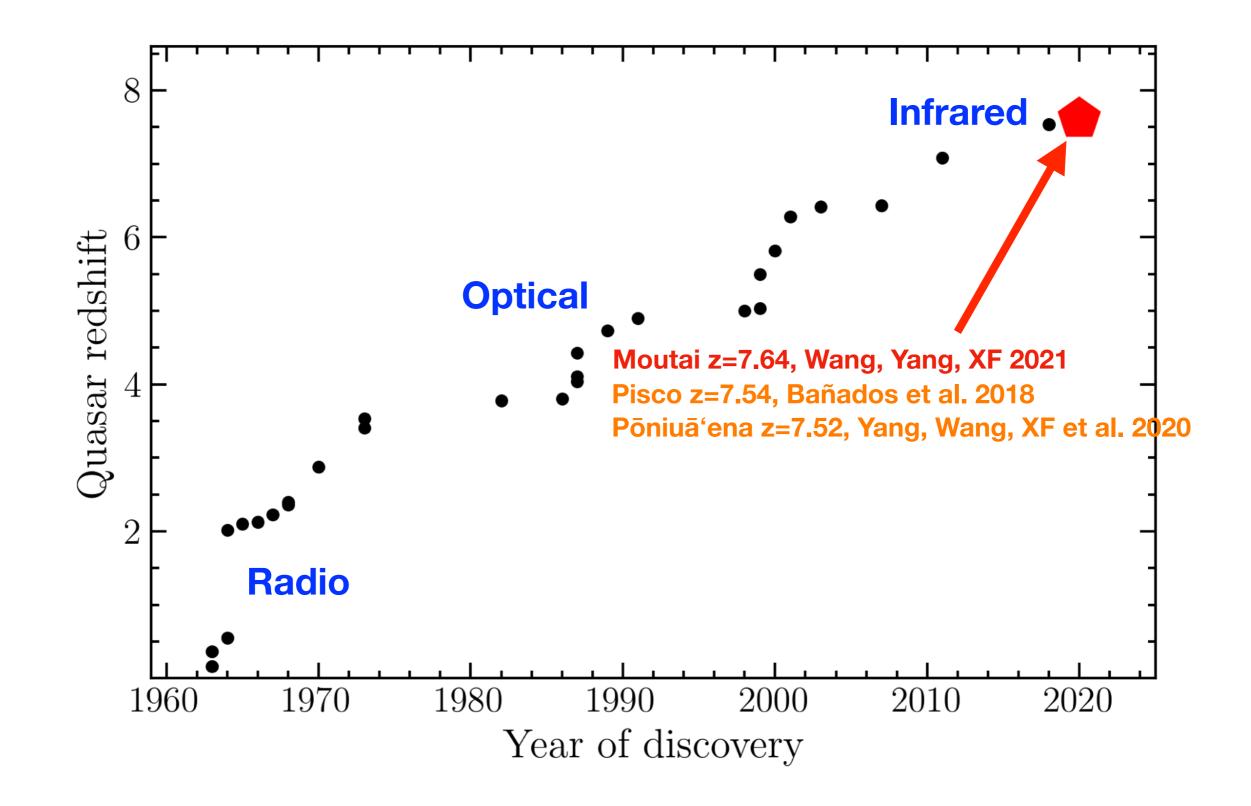
Xiaohui Fan (University of Arizona) Feige Wang, Jinyi Yang and collaborators

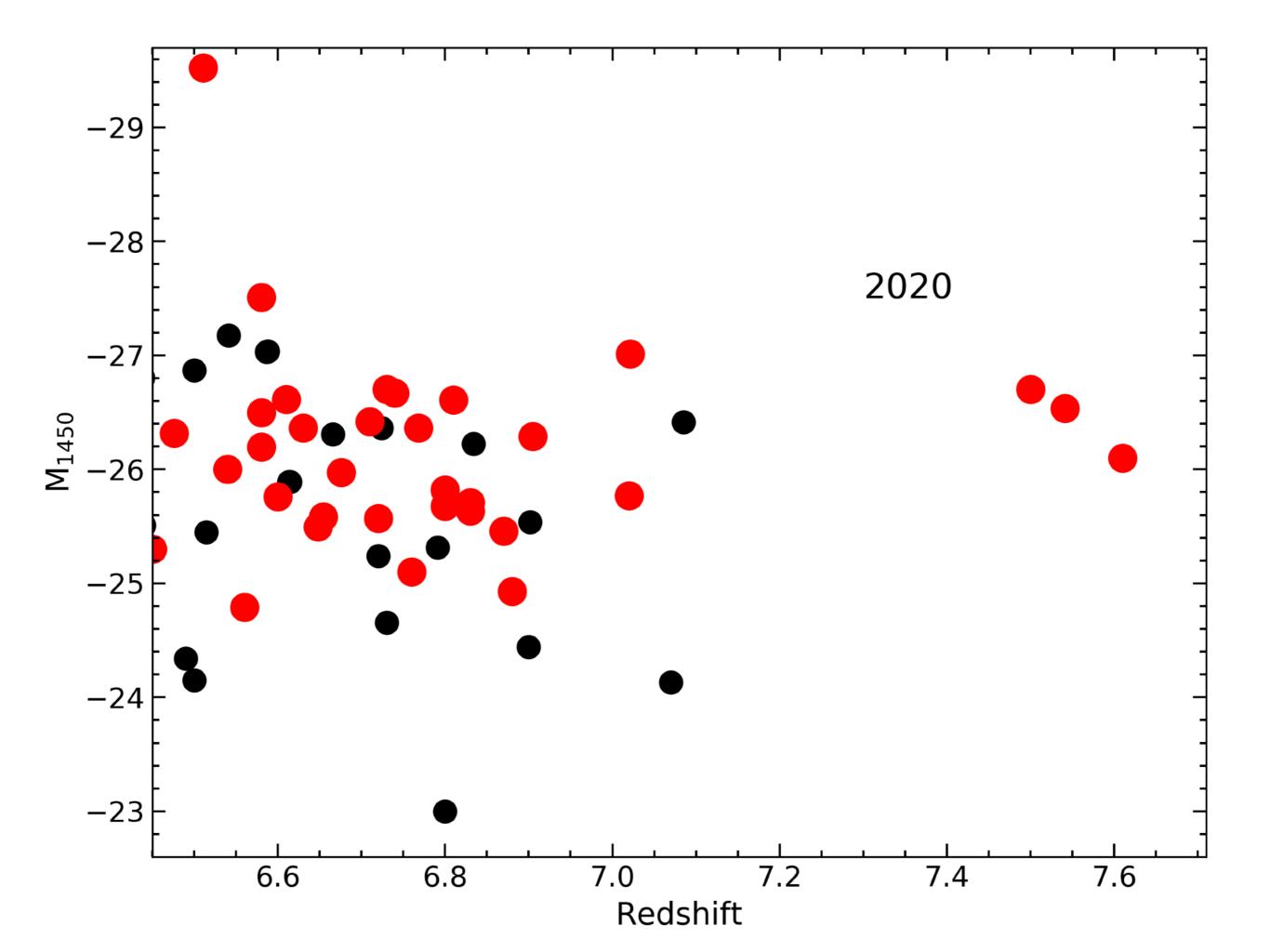
AAS Jan 2021

# Probing early universe with high-redshift quasars

- Epoch of the first luminous quasars:
  - can we reach z>10?
- Growth of early supermassive black holes:
  - massive BH seed needed?
- Environment of early quasars:
  - do they live in the most overdense environment and most massive galaxies?
- History of reionization:
  - when? sources? uniform or patchy?

### **The Highest Redshift Frontier Now**





# **Deep into the Reionization Epoch**

#### **Quasars at the End of Reionization**

J2329-0301, z=6.43 J1148+5251, z=6.42					
J1030+0524, z=6.28	1				
J0050+3445, z=6.25					
J1048+4637, z=6.23					
J1623+3112, z=6.22					
J0136+0226, z=6.21					
J0227-0605, z=6.20					
J1429+5447, z=6.18					
J0221-0802, z=6.16	~				
J2229+1457, z=6.15					
J1319+0950, z=6.13					
J1250+3130, z=6.13					
J0033-0125, z=6.13				~	
J2315-0023, z=6.12	~				
J1509-1749, z=6.12					
J2100-1715, z=6.09	~				
J0842+1218, z=6.08					
J1602+4228, z=6.07					
J0303-0019, z=6.07					
J2054-0005, z=6.06					
J2318-0246, z=6.05	~				
J1630+4012, z=6.05	~~				
J0353+0104, z=6.05					
J2310+1855, z=6.04	~				
J1641+3755, z=6.04					
J0055+0146, z=6.02					
J1137+3549, z=6.01			~~~~		
J0216-0455, z=6.01					
J2356+0023, z=6.00				<u> </u>	
7500 8000	8500	9000	9500	10000	10500

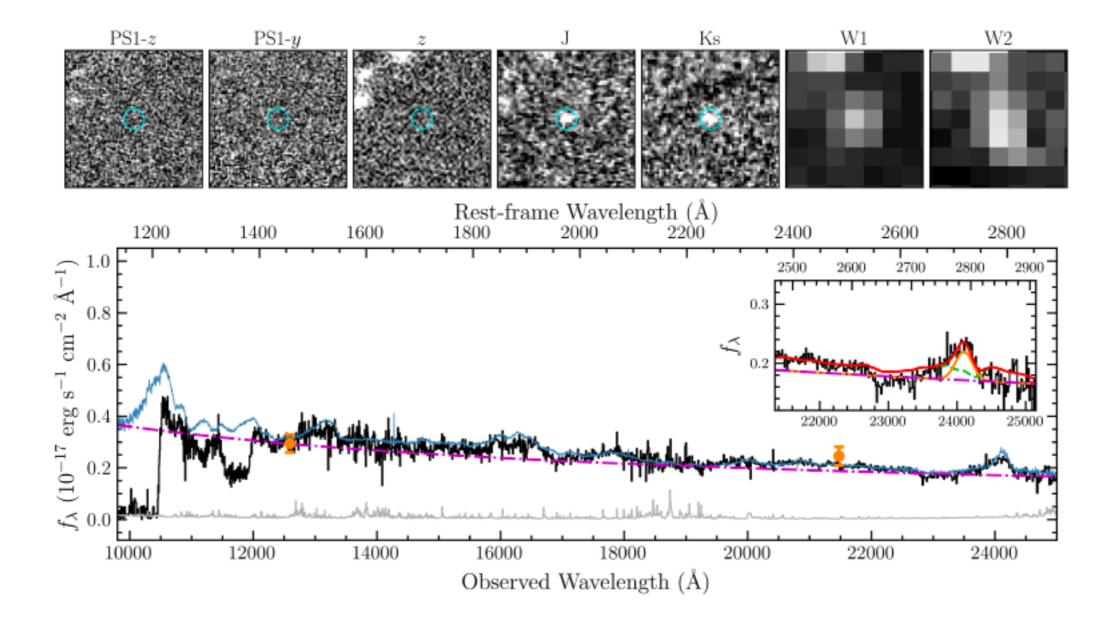
#### **Reionization-Era Quasars**

New Quasar, z=7.62	~~				
J1342+0928, z=7.54					~~~
New Quasar, z=7.52					
J0038-1527, z=7.02					
J0252-0503, z=7.0				m	
10820 + 2000 = -6.01					<u> </u>
J0839+3900, z=6.91			~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~	- former	
J2211-6320, z=6.88					
J0246-5219, z=6.87					
J0240-3219, z=0.87				mm	
J0411+0907, z=6.81			-		
J0829+4117, z=6.77				1 1 1 1 1	
J0829+4117, 2=0.77					
J1104+2134, z=6.74					
J0910+1656, z=6.72					
50510+1050, 2=0.12			- Martin		
J0837+4929, z=6.71					
J1048-0109, z=6.68					
J1216+4519, z=6.65			man		
J2102-1458, z=6.65			<u></u>		
	1.1.4.1.0.0.0.0				
J0910-0414, z=6.63					
J0923+0402, z=6.61					
			$\sim \sim $	~~~~	
J1135+5011, z=6.58					
J0706+2921, z=6.58					
		Y			
J0439+1634, z=6.51			~~~~		
7500 8000	8500	9000	9500	10000	1050
		velength	-		

#### From 2000 to 2010

From 2011 to Now

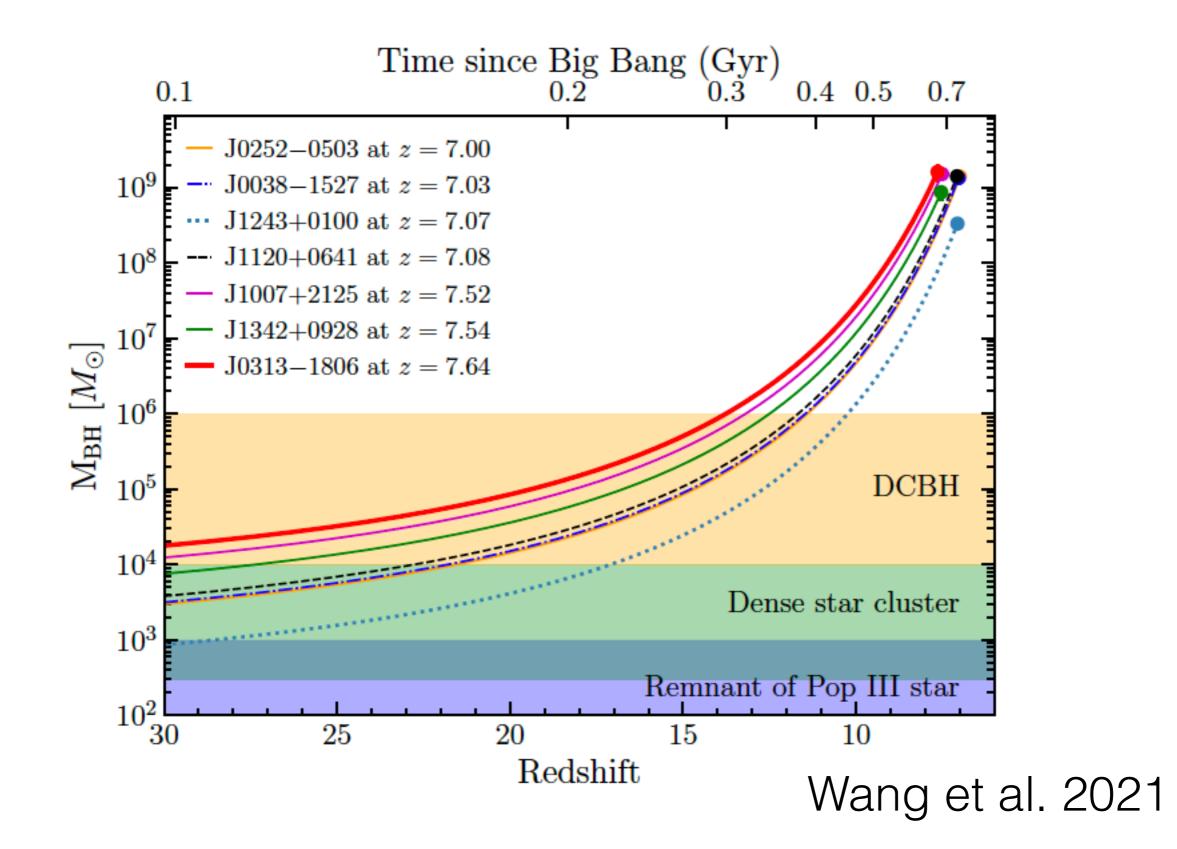
#### New Redshift Record Holder: J0313-1806 at z=7.64

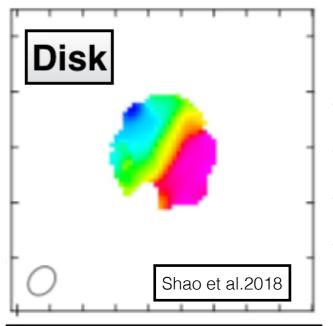


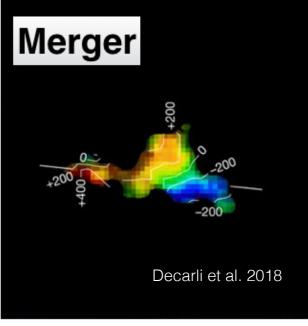
BH Mass: 1.6x10^9 M\_sun

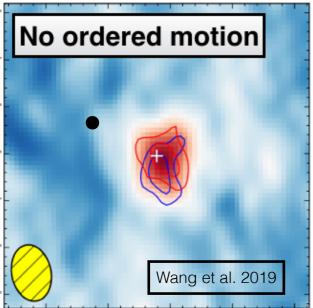
Wang et al. 2021

#### Constraints on BH seeds



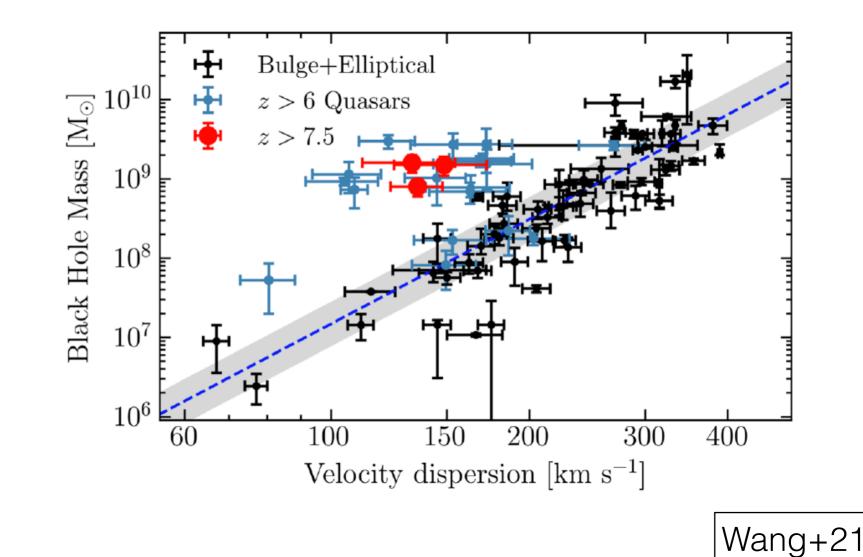




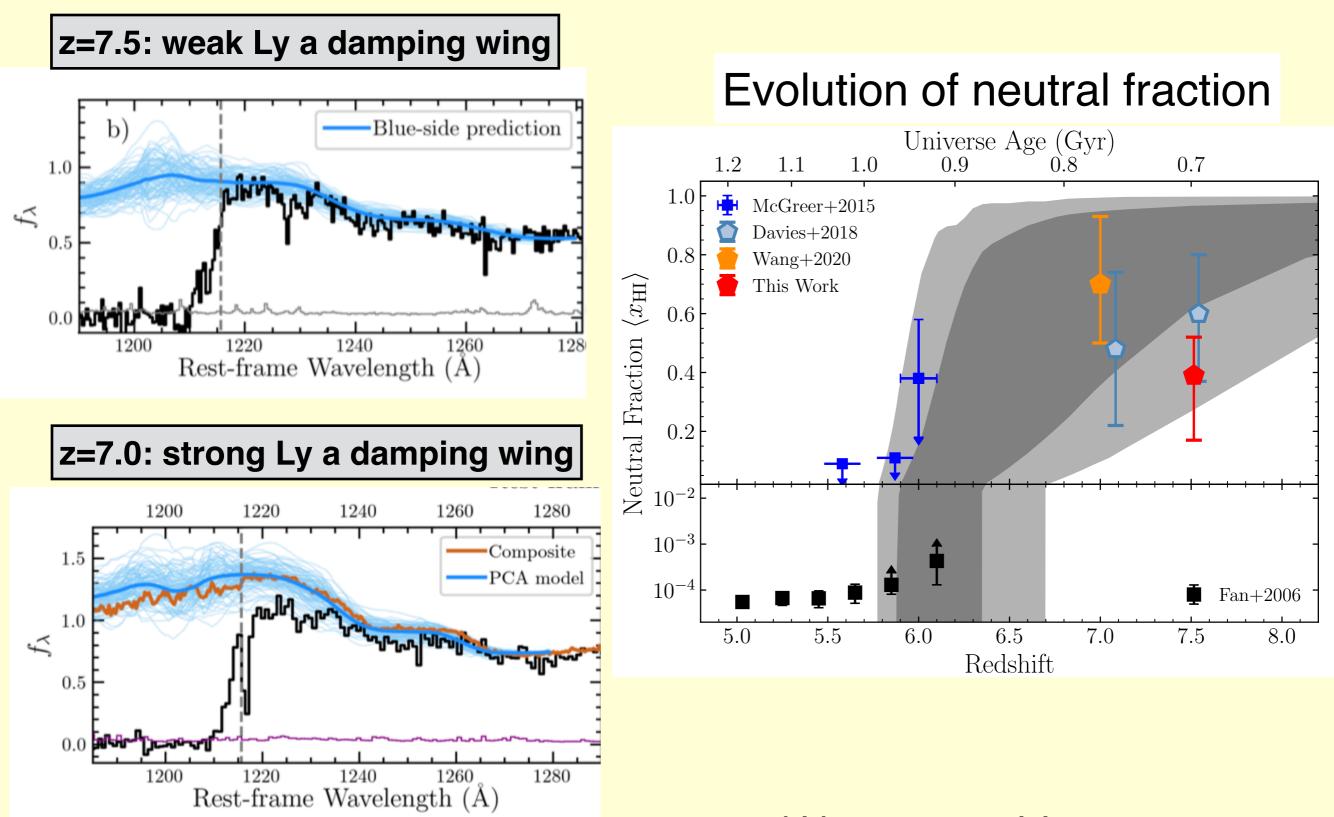


#### Co-evolution of BHs and galaxies? Or not?

- Kinematics from ALMA/[CII] with sub-kpc spatial resolution
- Diversity in host galaxy properties
- SFR ~100 few x1000 M\_sun/yr -> sites of massive galaxy assembly
- But with modest dynamical mass:
  - on average ~order of mag below local M-sigma relation
- No strong correlation between BH and SFR/mass of hosts

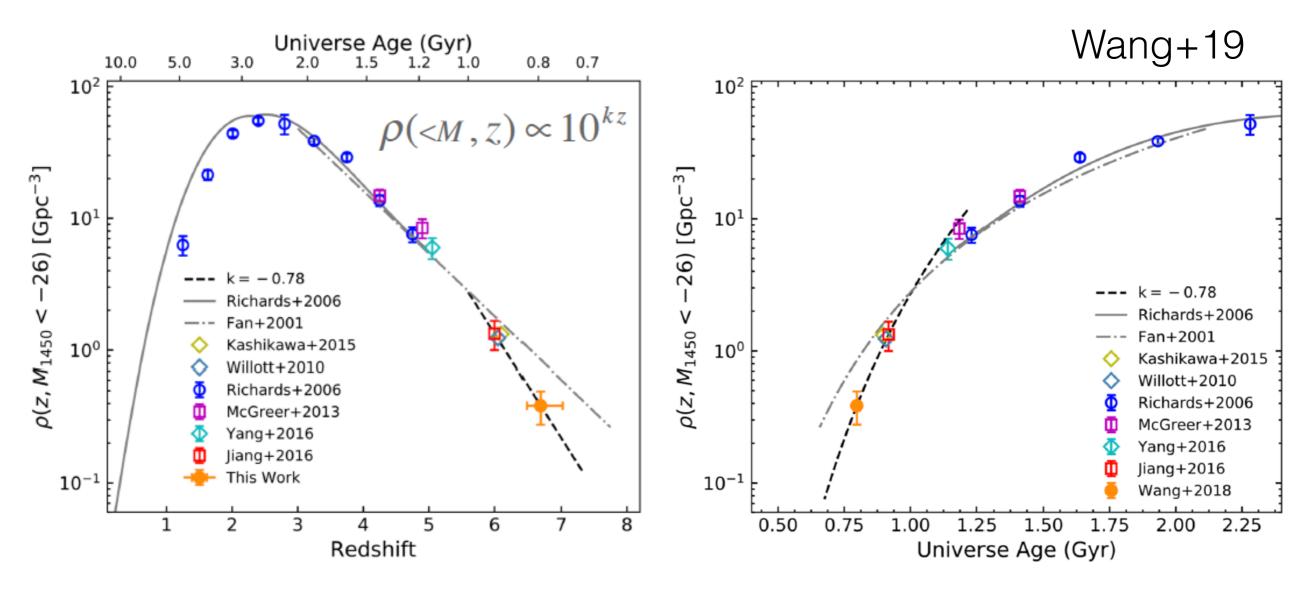


### **Patchy Reionization?**



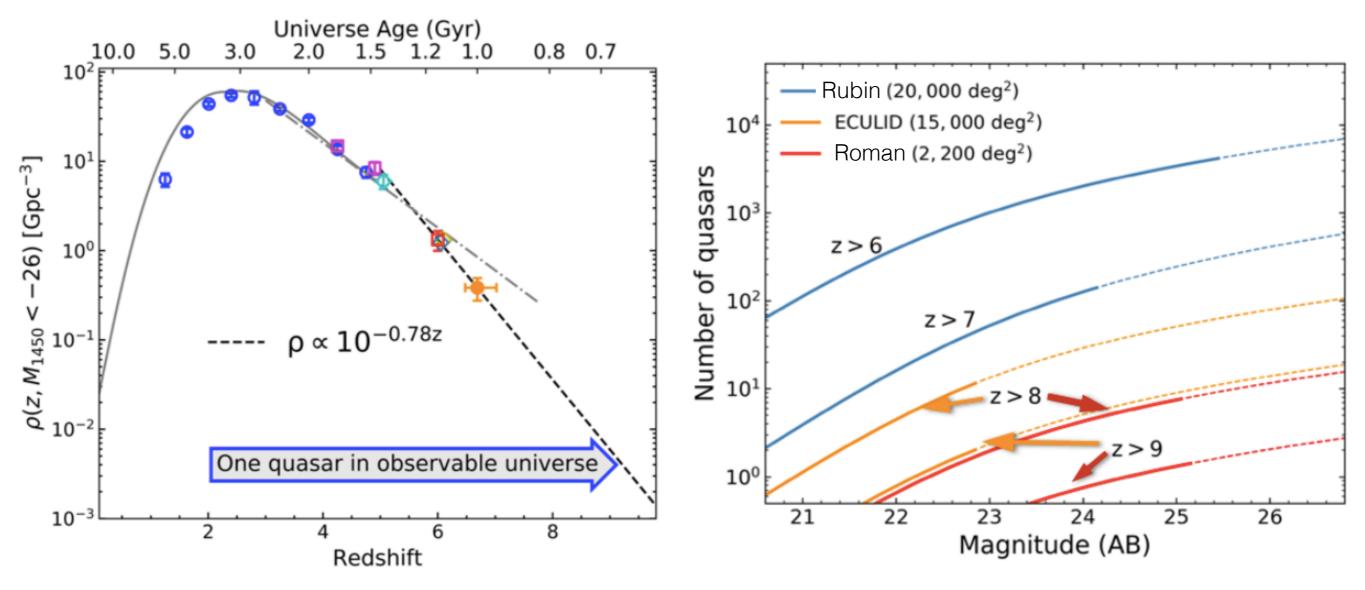
Wang+20, Yang+20

## closing in to the era of the first quasars



- first determination of quasar luminosity function at z~7
- quasar density evolution accelerated at z>6
- e-folding time for quasar density growth: 80 Myr (delta z = 0.6)
- comparable to Eddington timescale (45 Myr)
- quasar population growth is accretion-limited

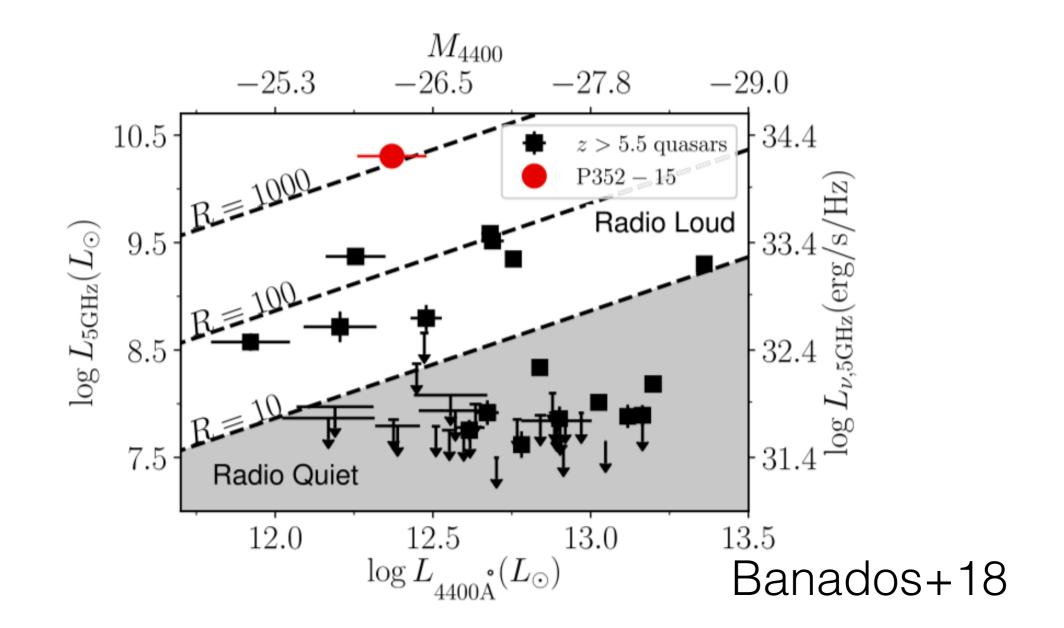
# the first quasars



- only ~1 quasar with billion M\_sun BH (M<-26) at z>9 in the observable universe -> the first quasars
- find them? Euclid/Roman + Rubin/LSST
- identify them? need spectroscopic identification of faint (AB~23-25) in IR -> JWST? ELTs?

# the first radio-loud quasars

- radio-loud fraction <=10% at z>6; no strong evolution in fluxlimited sample
- radio-loud quasars at z>6: 21cm forest to probe reionization
- ngVLA + deep-IR wide-field survey for discovery and followup



# Summary

- Combination of deep optical, near-IR and mid-IR photometric selection allows the first systemic surveys of luminous quasars at z>=7, with recent record-breaking discoveries of z>7.5 quasars
- Detection of Gunn-Peterson damping wings suggests a high IGM neutral fraction at z>7, and a rapid reionization at z=6-8 and considerable scatter
- Ten billion solar mass black holes at the end of reionization: direct collapse of large mass seed black holes in early universe
- The most distant quasars live in diverse galactic environment
- rapid decline in quasar density at z>6: first luminous quasar in the observable universe at z~9

Contact: Xiaohui Fan (xfan@arizona.edu), twitter: @xfan\_astro