AGN jets in the EHT era @Tohoku U., 20-22 Jan 2020

The radio-loud fraction of low-luminosity HSC quasars at z~6

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In collaboration with

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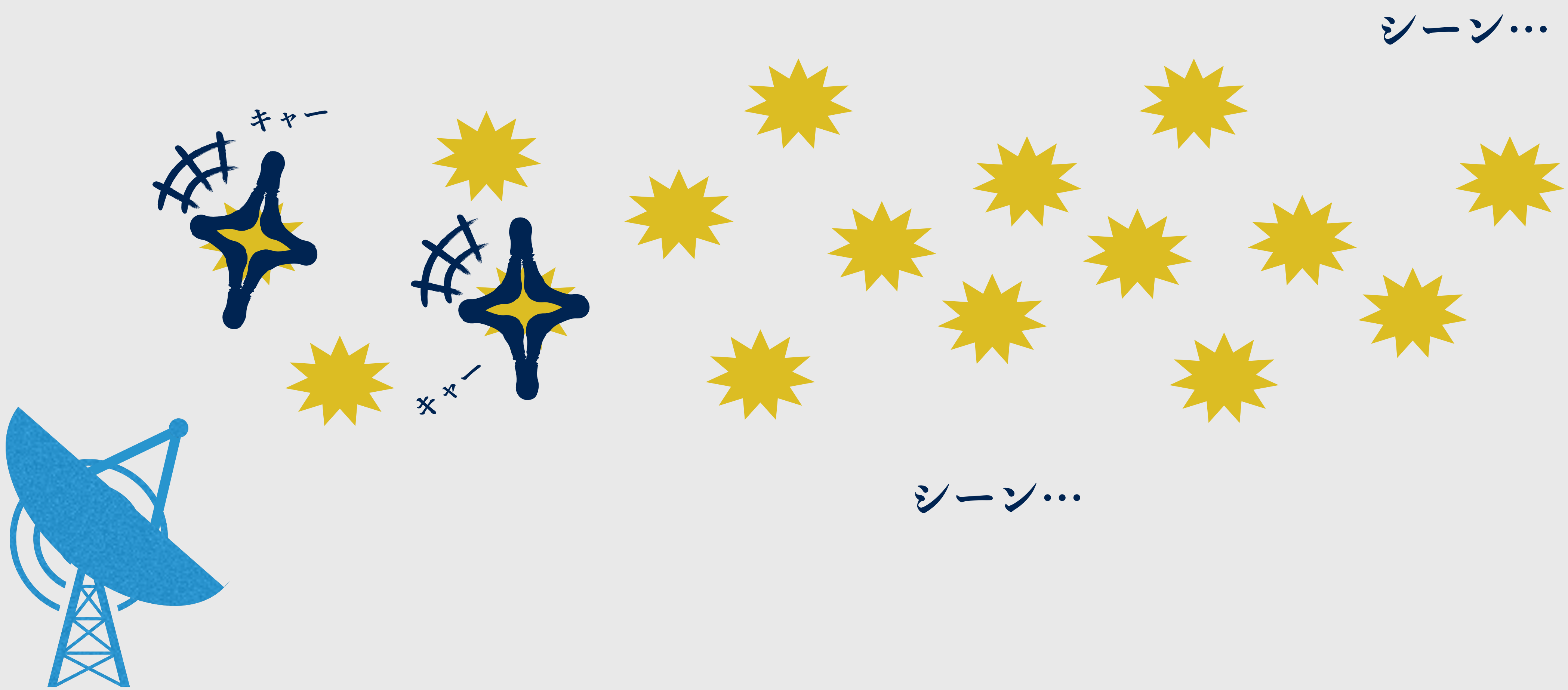
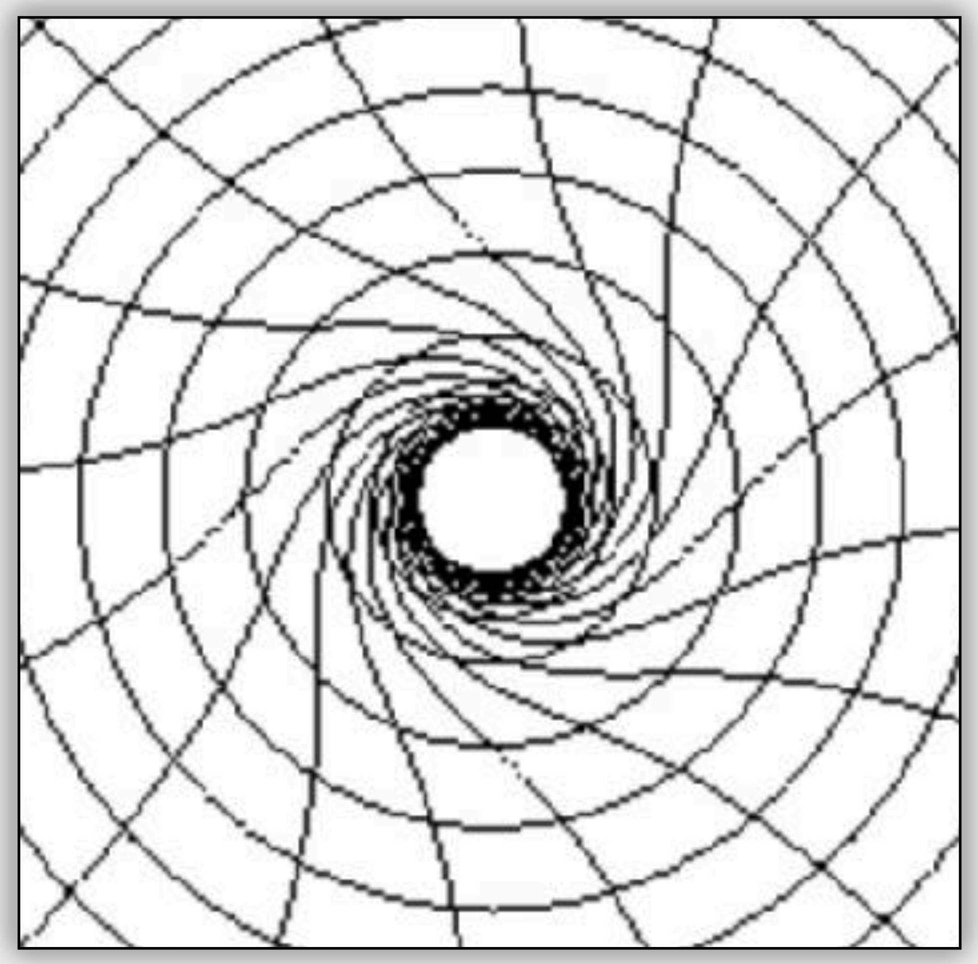
Quasars' radio properties

- Quasi-stellar 'radio' source
- Only 10-20% (e.g., Ivezić+02) show strong radio emission: 'Radio-loud'
- Hints on SMBHs' properties (e.g., mass, spin..)



The Kerr solution of GR— Spinning black hole

- Frame-dragging effect
- Static limit
  → all matter and light is forced to irresistibly rotate around the black hole
- Region within the static limit
  → ergosphere
- Rotational energy can be extracted from the ergosphere by magnetic fields (Blandford & Znajek 77)



© Michael Cramer Andersen 'Kerr's rotating Black Holes'

Radio-loudness: two definitions

- 1. Radio luminosity, e.g., $\log L_{5G}$= 25.5 (W/Hz) (Jiang+07)
  - Just based on a critical radio luminosity for radio-loud/quiet
- 2. Radio-to-optical flux density ratio, $R \equiv \frac{f_{5\mathrm{GHz}}}{f_{4400\text{Å}}}$ (Kellermann+89)
  - Extrapolating from monochromatic radio and optical data
  - Assume a power-law spectral energy distribution $f_\nu \propto \nu^\alpha$ in both optical and radio regions
  - Assumption of spectral indices:
    Radio: -0.75 Optical: -0.5
    (Wang+07; Bañados+15)
  - When *R* >10, classified as radio-loud

Radio-loud fraction evolution

- Dependences of the RLF on redshift and luminosity exist?

  — *Jiang+07: RLF ↘ when redshift ↗ and luminosity ↘*

- On the other hand, the mean radio-loudness…

  — *White+07: Mean radio-loudness ↗ when redshift ↗ and luminosity ↘*

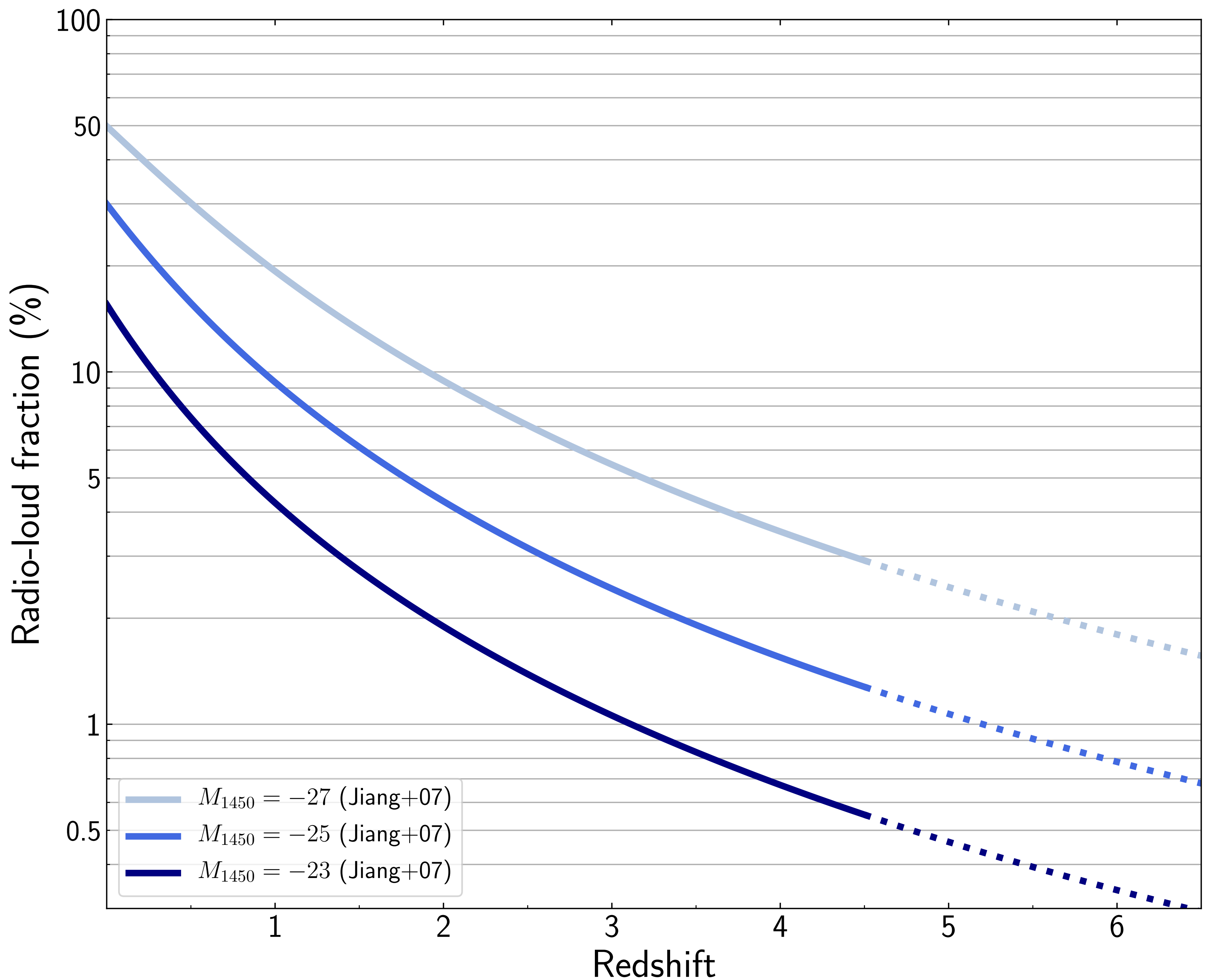
- **For a more evidential result, High-z study is important! but..**

  — *A high-z study (z>5.5, Bañados+15) shows a similar result with local studies, suggesting that there's no such evolution.*

  — *Probably they are biased by the luminous sample at high-z?*

- **We need high-z low-luminosity samples!**

Radio-loud fraction evolution



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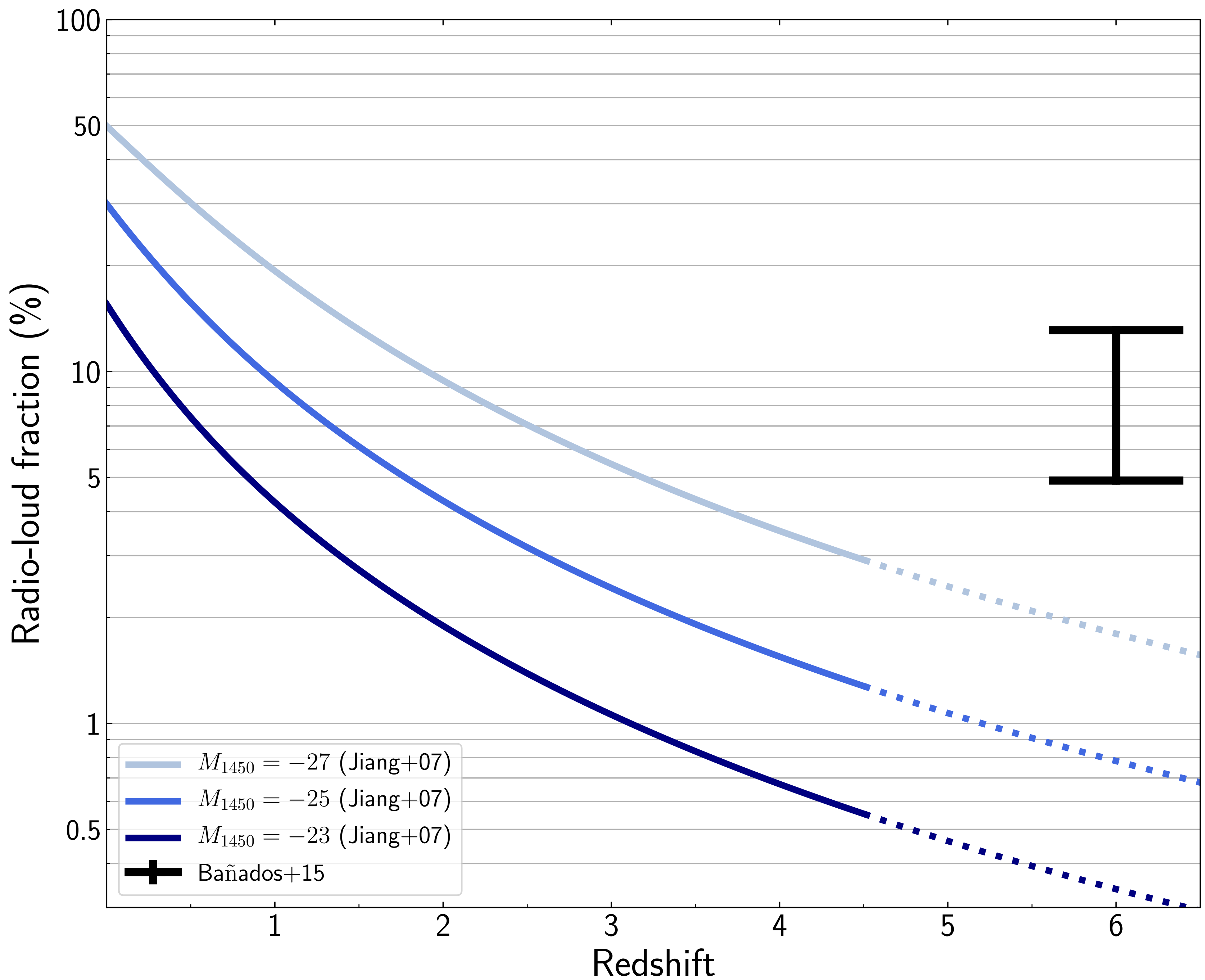

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Subaru/HSC-selected quasars

- Discovered with the Hyper Suprime-Cam Subaru Strategic Program survey (Aihara+18)

- HSC: a wide-field image camera mounted on Subaru telescope

Layer	Area (deg^2)	Filters	i-band depth (mag)
Wide	1400	$g\ r\ i\ z\ y$	25.9
Deep	26	$g\ r\ i\ z\ y$ +3NBs	26.8
UltraDeep	3.5	$g\ r\ i\ z\ y$ +3NBs	27.4

Survey	Filters					
SDSS[a]	u	g	r	i	z	
depth (mag)[e]	22.3	23.3	23.1	22.3	20.8	
Pan-STARRS1[b]		g	r	i	z	y
depth (mag)[e]		23.3	23.2	23.1	22.3	21.4
DES[c]		g	r	i	z	Y
depth (mag)[e]		25.2	25.1	24.3	23.7	22.5
HSC-SSP Wide[d]		g	r	i	z	y
depth (mag)[e]		26.5	26.1	25.9	25.1	24.4

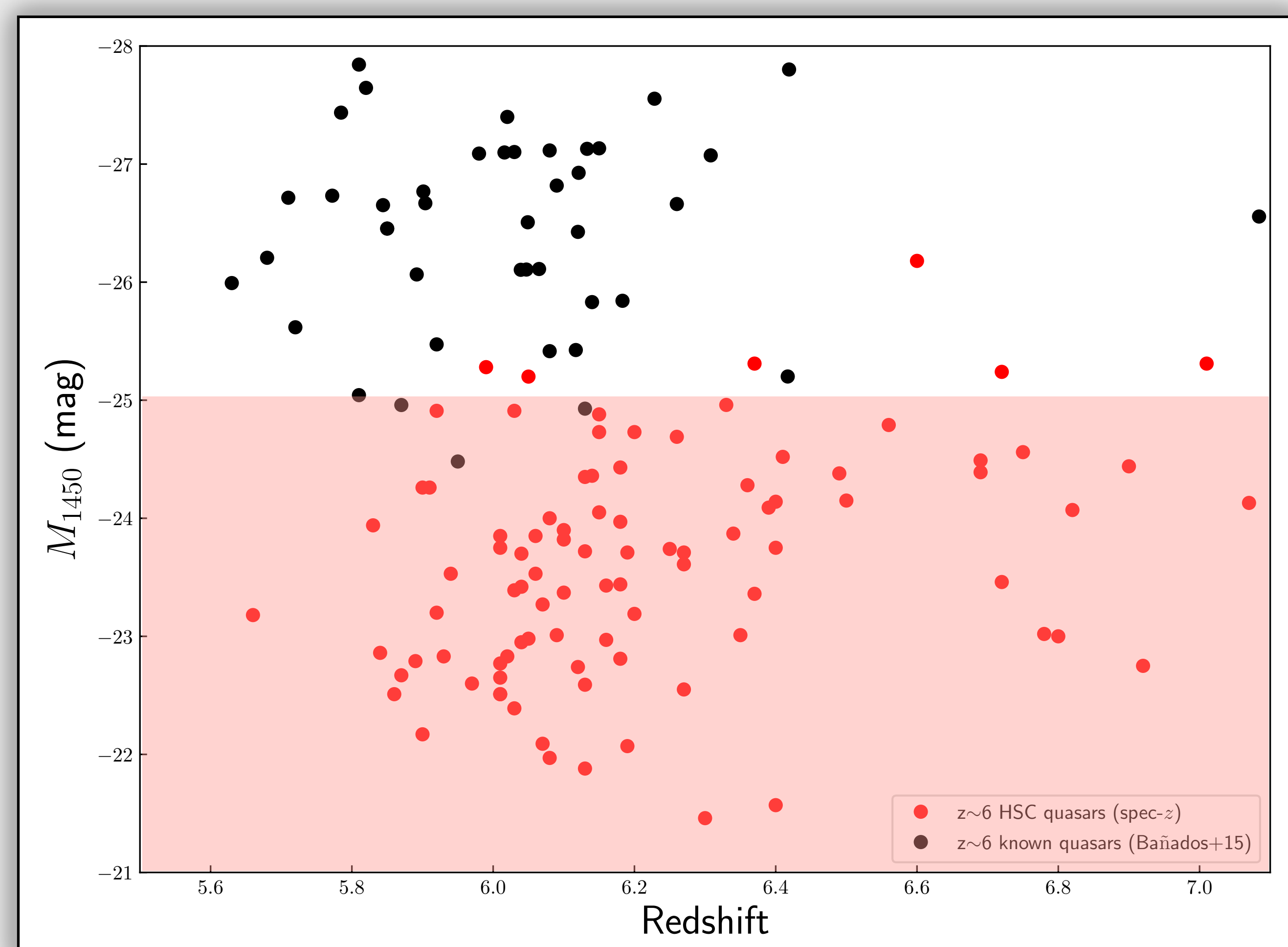
[a] York et al. (2000)
[b] Chambers et al. (2016)
[c] Dark Energy Survey Collaboration et al. (2016)
[d] Aihara et al. (2018)
[e] 5σ detection limit

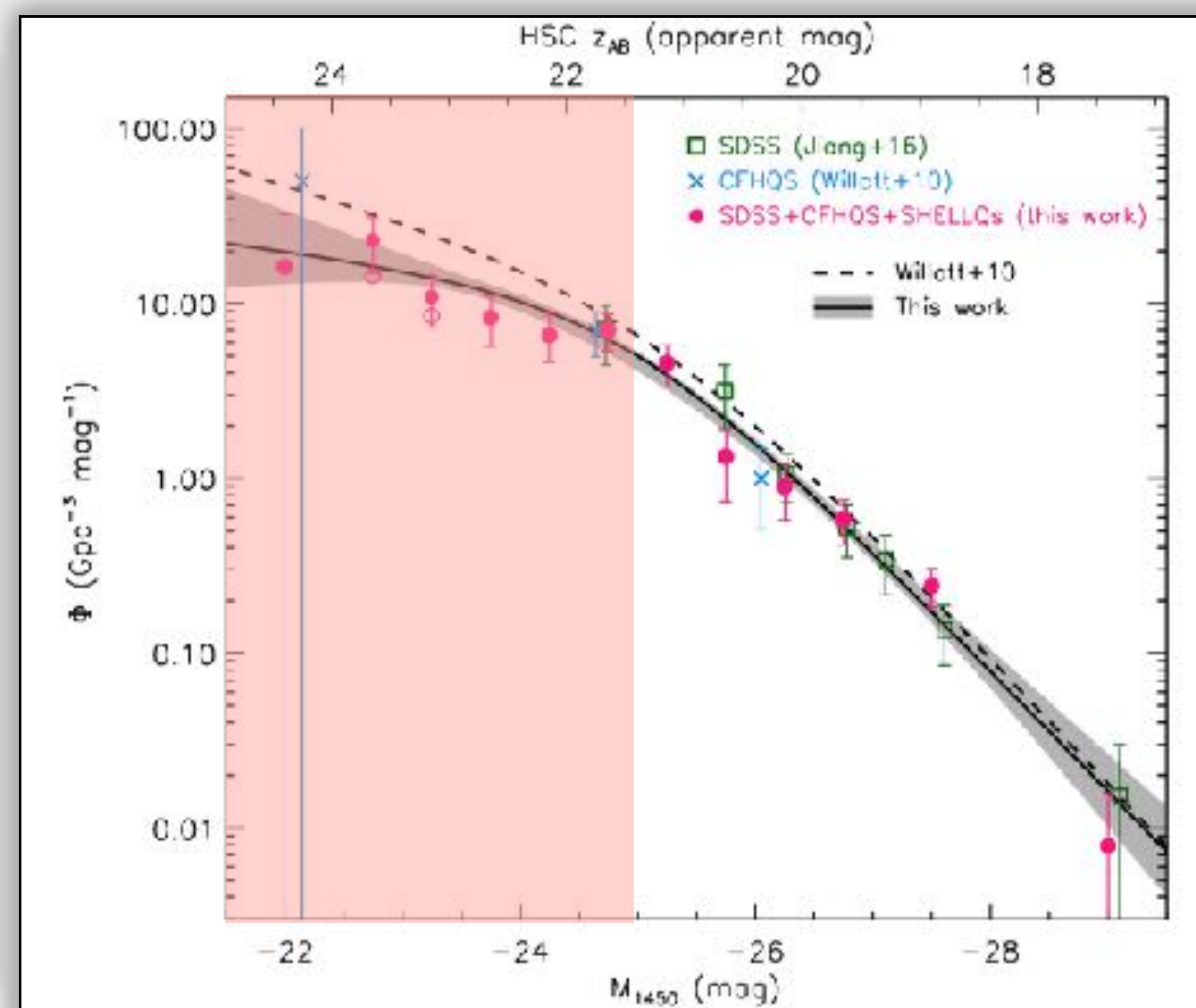
- High-z (z~4-6)

- Low-luminosity (M_{1450} >-26)

Subaru/HSC-selected quasars

- Subaru High-z Exploration of Low-Luminosity Quasars (SHELLQs) (Matsuoka+16, 18ab, 19b) — 93, over 900 deg²
- Color-selected and identified with spectroscopic follow-up observations





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Radio data — VLA-FIRST and JVLA follow-up

- **Archive**
  - VLA-FIRST survey (150 μJy; Becker+95)
  - Stripe 82 (50 μJy; Hodge+11)
- **Observations**
  - Karl G. Jansky Very Large Array (JVLA)
    18A-316: March - June, 2018
    19A-317: August - October, 2019
  - 23 HSC quasars observed
  - Frequency: 1.4 GHz (~20 cm)
  - Angular resolution: ~2”
  - Sensitivity (1σ): ~10-50 μJy

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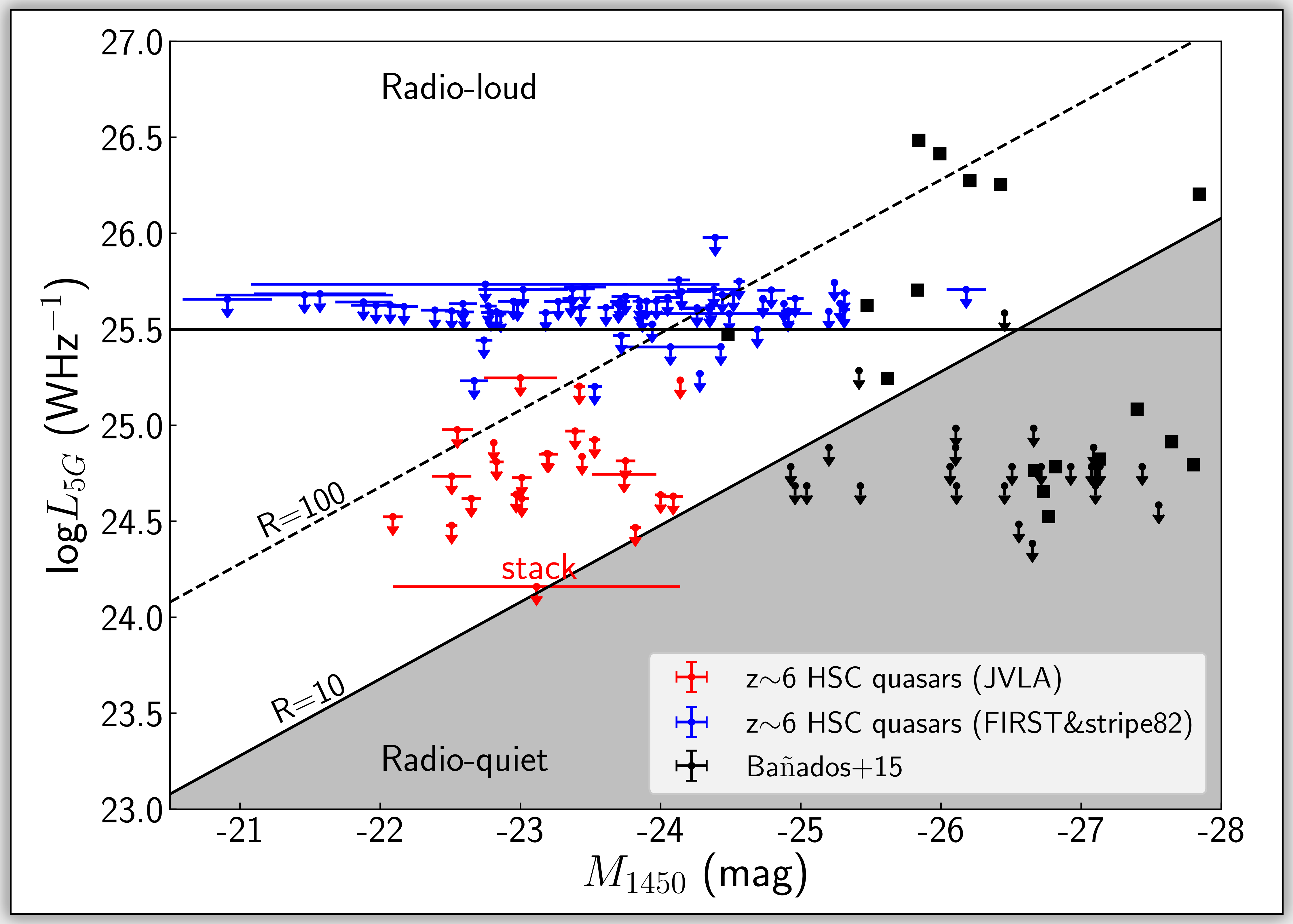
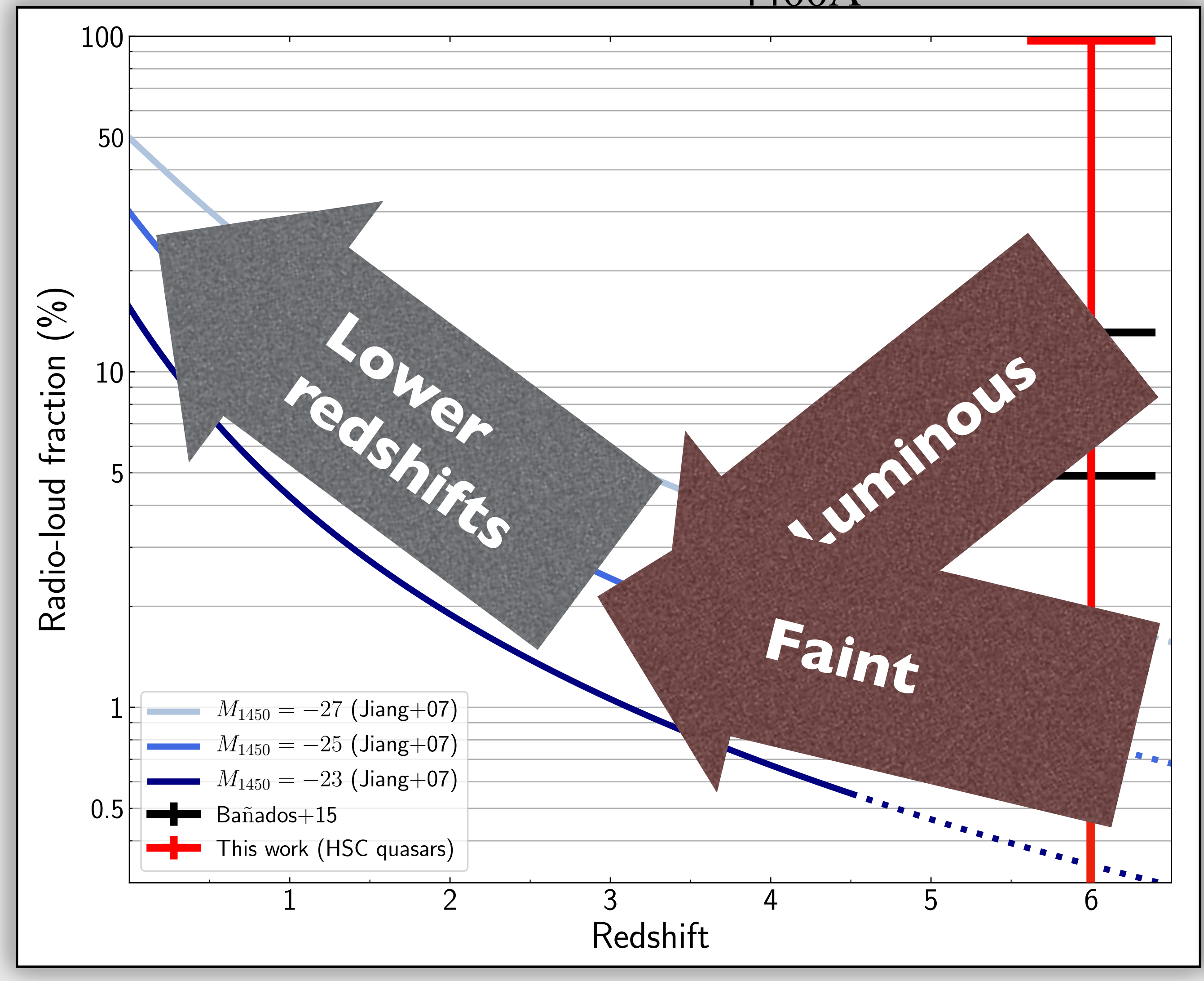
Result

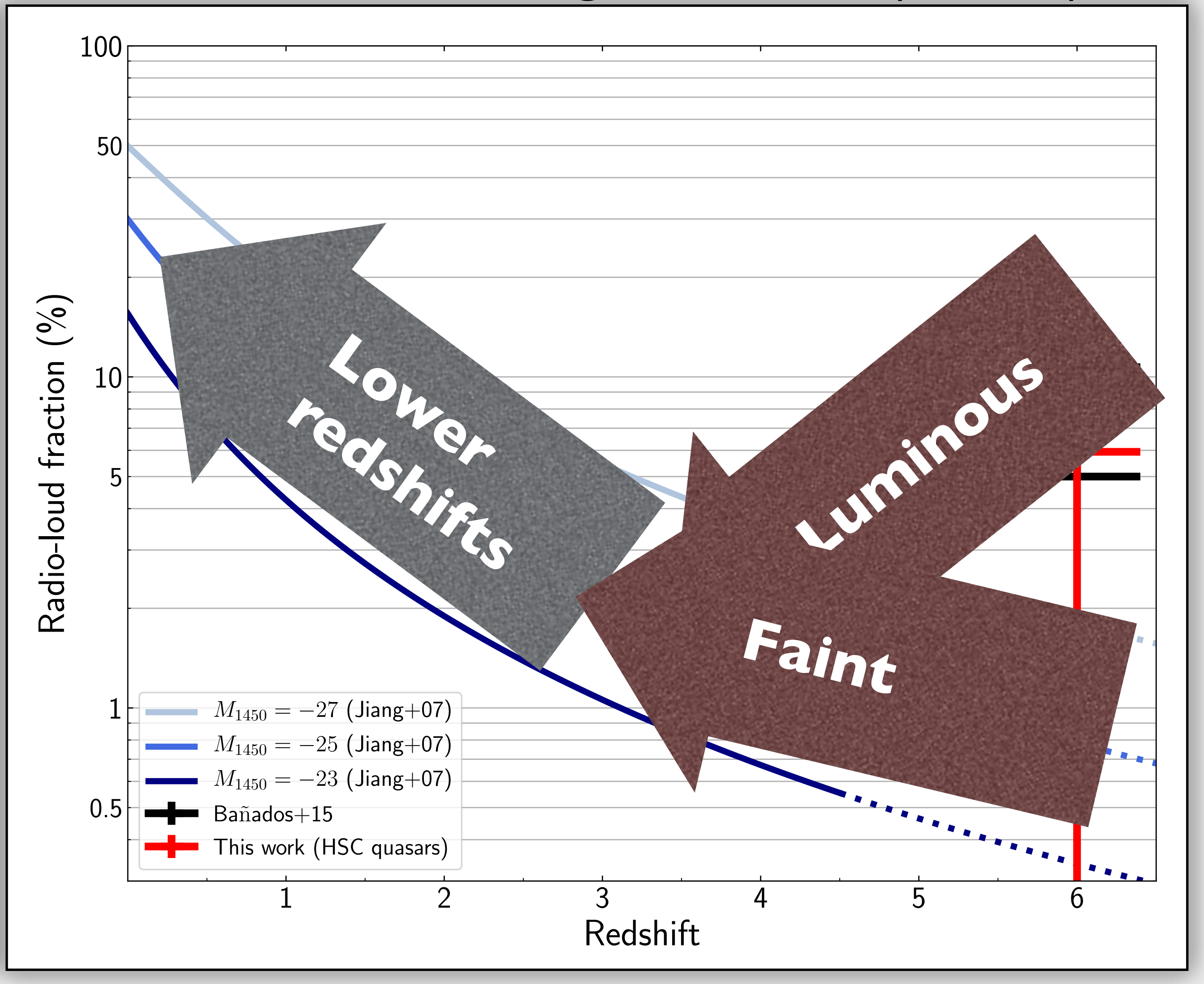

Radio-loud
Radio-quiet
R=100
R=10
stack
$\log L_{5G}$ (WHz^{-1})
M_{1450} (mag)
27.0
26.5
26.0
25.5
25.0
24.5
24.0
23.5
23.0
-21
-22
-23
-24
-25
-26
-27
-28
z~6 HSC quasars (JVLA)
z~6 HSC quasars (FIRST&stripe82)
Bañados+15

The radio-loud fraction

Radio-loudness: $R \equiv \dfrac{f_{5\mathrm{GHz}}}{f_{4400\text{Å}}}$

Radio-loudness: critical radio luminosity
$\log L_{5G} = 25.5$ (W/Hz)





A great fraction of SMBHs have high spin in luminous quasars?
The formation of SMBHs in the early universe makes them spin-up?

- We cross-matched z~6 HSC quasars with
  - archival radio survey (FIRST; σ = 150 μJy @1.4 GHz)
  and conducted
  - new JVLA observations (23 sources; 10-50 μJy @1.4 GHz)

- None of 93 HSC quasars are classified as radio-loud.

- The radio-loud fraction of HSC quasars at ~6:
  - 0-97% (not constraining) using $R = \frac{f_{5\mathrm{GHz}}}{f_{4400\mathrm{\AA}}} = 10$ as threshold
  - 0-5.9% using the critical radio luminosity $\log L_{5G}$= 25.5 (W/Hz) as threshold

- The radio-loud fraction of HSC quasars is lower than that of luminous quasars.