Search for high-z radio galaxies by Subaru HSC and FIRST catalogs

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Radio Galaxies

Important population in evolution/formation of AGNs/galaxies

- Powerful radio jets – AGN feedback, formation of massive galaxies
- Massive host galaxies – Formation of massive galaxies
- Overdense environment (high-z) – AGN, formation of massive galaxies and cluster

**Definition**

- \( L(5\mathrm{GHz})/L(B) > 10 \)  
  \[ \text{[Kellermann et al. 1989]} \]
- \( L(1.4\mathrm{GHz}) > 10^{24} \mathrm{W/Hz} \)  
  \[ \text{[Tadhunter 2016]} \]

Very Bright in radio → valuable probe to high-z galaxies

**Hercules A radio galaxy (HST&JVLA)**
Radio Galaxies at $z > 1$

- Redshift evolution of Radio Galaxies
- $z > \sim 1$ universe is particularly important epoch
  - a growth period of BH and Star formation
  - a build-up of stellar mass in massive elliptical galaxies

Madau & Dickinson 2014
Radio Galaxies along redshift

- Evolution of Radio Galaxies themselves is standing question
- z>~1 universe is particularly important epoch
  - a growth period of BH and Star formation
  - a build-up of stellar mass in massive elliptical galaxies

Tamburri et al. 2014
Radio Galaxies along redshift

- Evolution of Radio Galaxies themselves is standing question
- $z \approx 1$ universe is particularly important epoch
  - a growth period of BH and Star formation
  - a build-up of stellar mass in massive elliptical galaxies

How did Radio Galaxies behave at $z > 1$?

![Graph showing mass fraction vs. redshift for LTG and ETG](image)

Tamburri et al. 2014
Previous Statistic Studies: Low-z RGs

- Few identified high-z radio galaxies
- Almost all the identified RGs are at $z < 1$

- SDSS - FIRST sample
  - $z < 1$
  - Matching rate $\sim 30\%$ (Ivezic et al. 2002, Helfand 2015, Ching et al. 2017), even if complex radio morphologies are included.

Optically faint host galaxies
Low space density (a few/deg$^2$/mag)

Redshifts of spectroscopically identified RGs

FIRST 1.4GHz VLA Survey

Khabibullina & Verkhodanov 09

cf. Henfand+15
Search for radio galaxies with HSC & FIRST

Subaru HSC-SSP
- Wide-field imaging survey with g,r,i,z,y multi-band filters
- Wider and deeper (Aihara et al. 2017)

<table>
<thead>
<tr>
<th></th>
<th>Wide</th>
<th>Ultra-Deep</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limiting mag i [mag]</td>
<td>26.4</td>
<td>27.0</td>
</tr>
<tr>
<td>Area [deg²]</td>
<td>178</td>
<td>4</td>
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</tbody>
</table>

- HSC-SSP enables us to detect RGs with a higher redshift and/or a higher radio-loudness

FIRST 1.4GHz survey
- 1.4 GHz (20 cm) continuum
- Area = 10,575 deg²; ~ the SDSS region
- Detection limit = 1 mJy
  - Relatively shallow sensitivity
    → Detections of radio-AGNs ($L_{(1.4GHz)} > 10^{24}$ W/Hz) rather than star-forming galaxies at $z > 0.5$
- Angular resolution = 5”
- Astrometry < 0.5”
### Subaru HSC - FIRST cross match

<table>
<thead>
<tr>
<th></th>
<th>FIRST</th>
<th>HSC</th>
<th>Matches</th>
<th>Matches/FIRST</th>
<th>Chance coincidence</th>
<th>Completeness</th>
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</thead>
<tbody>
<tr>
<td><strong>Wide</strong></td>
<td>8,282</td>
<td>23,795,523</td>
<td>8,282</td>
<td>23,795,523</td>
<td>Preliminary</td>
<td></td>
</tr>
<tr>
<td><strong>UD-COSMOS</strong></td>
<td>118</td>
<td>643,932</td>
<td>118</td>
<td>643,932</td>
<td>Preliminary</td>
<td></td>
</tr>
</tbody>
</table>

- **Positional matching** between FIRST and Wide / UD-COSMOS with a search radius = 1”
- **Radio-core**: we focus on matching to radio-core; complex morphology radio sources is minor (10%)
HSC & FIRST Images

HSC i
10” x 10”

FIRST
2’ x 2’

Preliminary
Radio loudness (observed frame)

- Radio loudness,
  \[ R = \frac{F(\text{radio})}{F(\text{optical})} = \frac{F(1.4\,\text{GHz})}{F(i\text{-band})} \]
- **Optically faint radio sources** have high observed-frame \( R \)
- Such rare objects are found in the Wide survey (●, ▲) rather than the Ultra-Deep (●, ▲).
Photo-z of the HSC-FIRST samples

- Mizuki SED template fitting (Tanaka 2015)
- xxxx (xx) HSC-FIRST Wide (UD) RGs have secure photo-z
- Almost all the samples have photo-z of 0.2 - 1.5
- **Optically faint (HSC-level) RGs** are located at \( z \approx 1 \)
Radio loudness at the rest-frame

- Rest-frame $R = \text{rest 5GHz flux} / \text{rest g-band flux}$
  - rest 5GHz flux = $k$-corrected obs-1.4GHz with radio-index $\alpha = -0.7$ and $z_{\text{photo}}$
  - rest g-band flux = a production from Mizuki SED template fitting
- Even when $R$ is $k$-corrected, optically faint ($z \sim 1$) RGs show high $R$.

![Graph showing log $R_{\text{rest}}$ vs. $i$ (cModel) [AB mag] and photo-z.](Diagram)
Optical color

- HSC-level RGs have a large dispersion of color
- We have high R and blue color sources
Blue Radio Galaxies

SDSS-level (i<21.3 mag)

- local z<1
- red g-z: elliptical host galaxies

Preliminary
Blue Radio Galaxies

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HSC-level (i>21.3 mag)
- redshifted, z>1
- large dispersion in g-z (= rest UV @z~1)
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\[\text{i (cModel) [AB mag]}\]

\[\text{g - z [AB mag]}\]

Preliminary
Blue Radio Galaxies

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HSC-level (i>21.3 mag)
- redshifted, z>1
- large dispersion in g-z (= rest UV @z~1)
- Blue g-z
  - relatively young elliptical galaxies (post-starburst) ?
  - AGN light

\[ i (cModel) \ [AB \ mag] \]
\[ g - z \ [AB \ mag] \]

Preliminary
High Excitation Radio Galaxies

- Blue color RGs are similar to HERGs (high-excitation RGs)
- HERGs have young stellar population & low stellar mass, suggesting jets via cold-gas accretion triggered by galaxy-merger (Best & Heckman 2012).

- HERGs show no Broad emission lines (Ching+17)
  - Blue color may comes from star formation

Need spectroscopy
Summary

- To create high-z (z>~1) RG sample, we started the search for HSC-FIRST RGs
- We successfully identified > xxxxx radio sources in ~xxx deg$^2$ field.
  - Subaru HSC-SSP provides good opportunities to probe high-z RGs.
  - Optically faint RGs are located at z~1, and have higher radio-loudness and bluer color than bright RGs.
  - They show similar characteristics to HERGs.

- Future work
  - Spectroscopy z>1 RGs
  - Optical morphology and clustering will be investigated.