ICRAR

International Centre for Radio Astronomy Research

Radio Survey Synergies with Euclid

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Galaxy Evolution with Euclid and ESO

Curtin University

The Government of Western Australia

The University of Western Australia

Radio Astronomy Landscape

VLA

MERLIN

WSRT

ATCA

LOFAR **JVLA** **MWA** **eMERLIN** **MeerKAT** **APERTIF** **ASKAP** **ATCA** **ALMA**

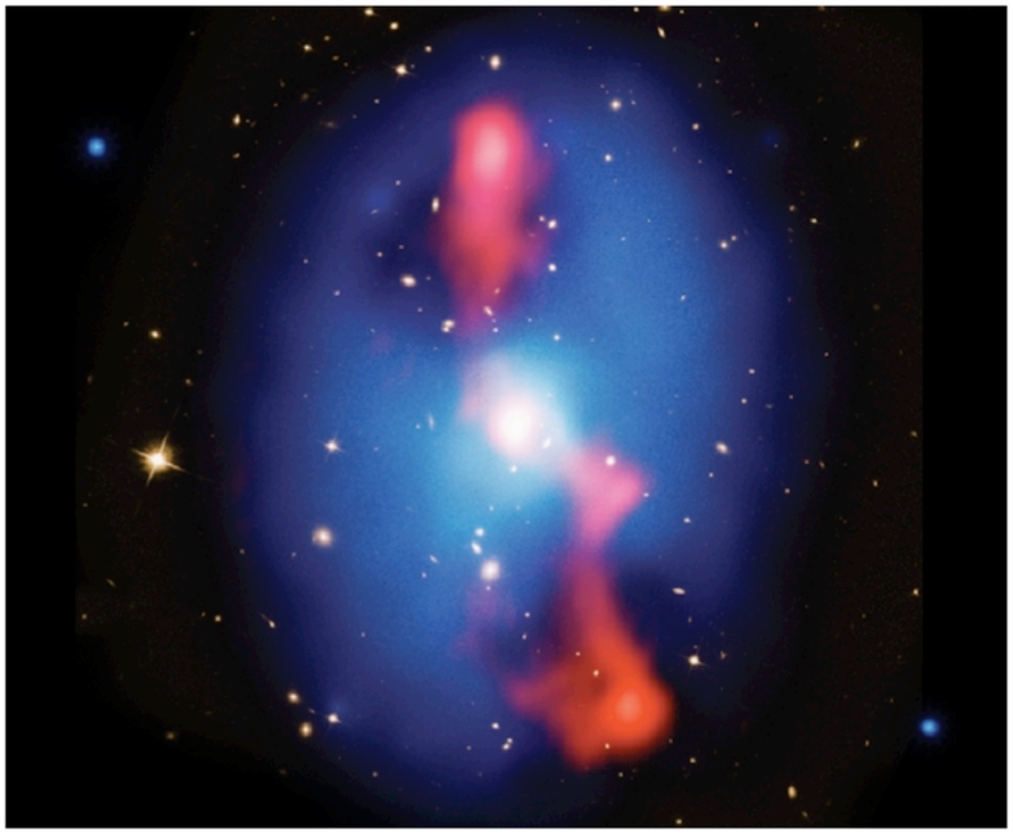
Versatility of Radio Surveys

Vast range of science

- **galaxy/AGN evolution**
- **high-z Universe**
- jets on all scales
- black holes
- magnetic fields
- **(proto-)clusters**
- Milky Way
- local Universe
- cosmic rays
- pulsars, FRBs, magnetars
- gravitational waves
- solar studies
- ionosphere
- interstellar medium
- intergalactic medium
- CMB
- EoR
- **other cosmology**
- SETI & Cradle of Life

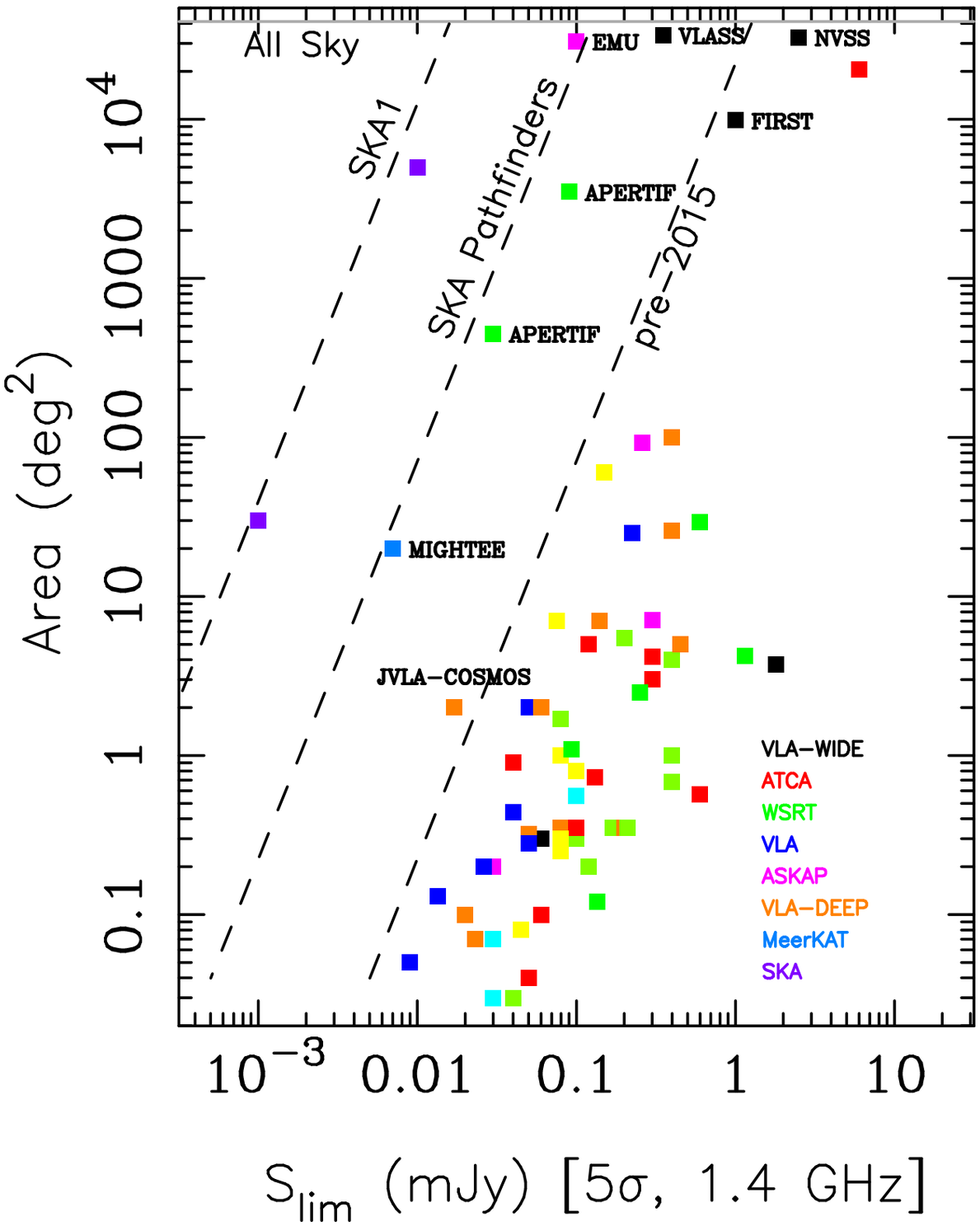
Proto-clusters

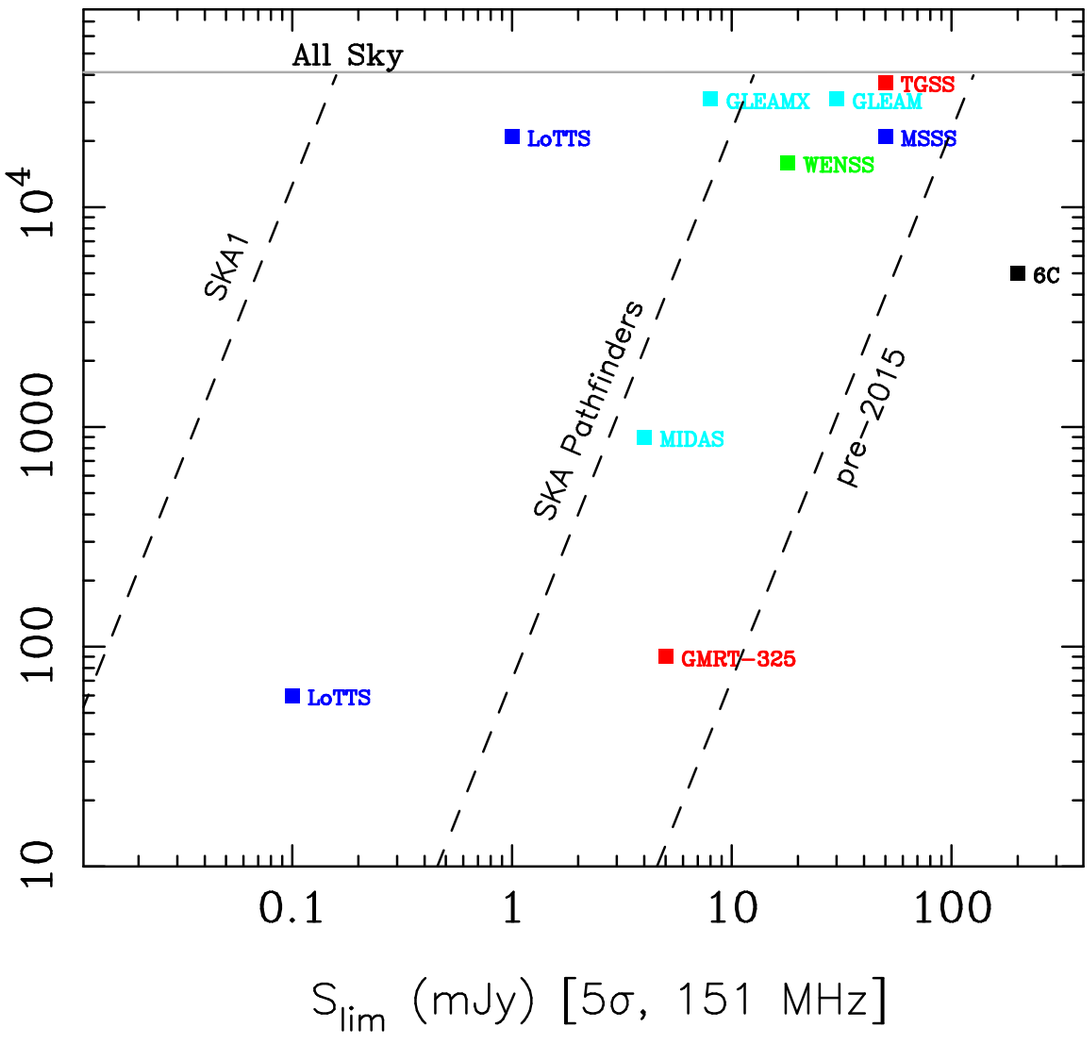
- already covered by Helmut Dannerbauer and Tadayuki Kodama
- with independent sample of proto-clusters, studying the frequency of radio galaxies can lead to an accurate determination of their duty cycle. **RGs impact host cluster!**



Gitti et al. (2011)

Survey Parameters

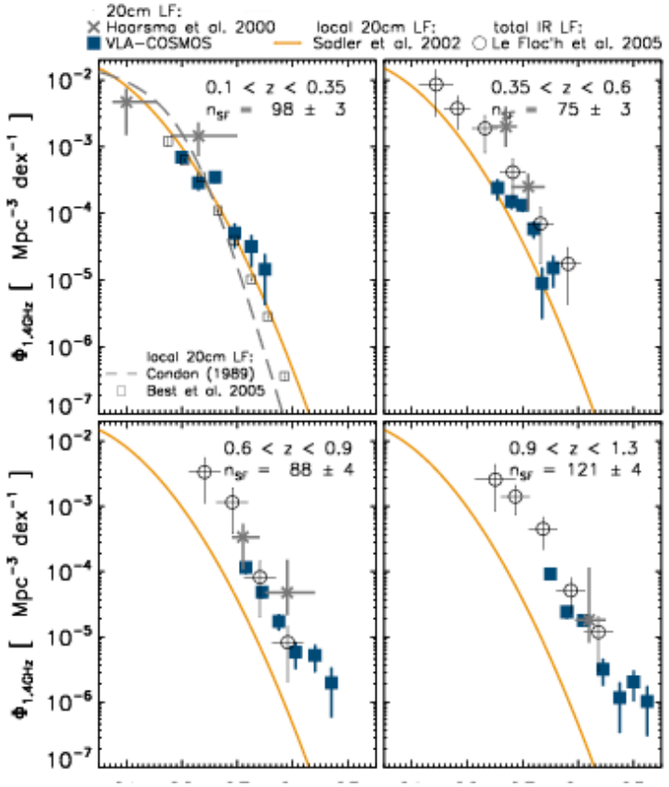




MWA
- large FoV
- low surface brightness sensitivity
- wide spectral range (70-230 MHz)

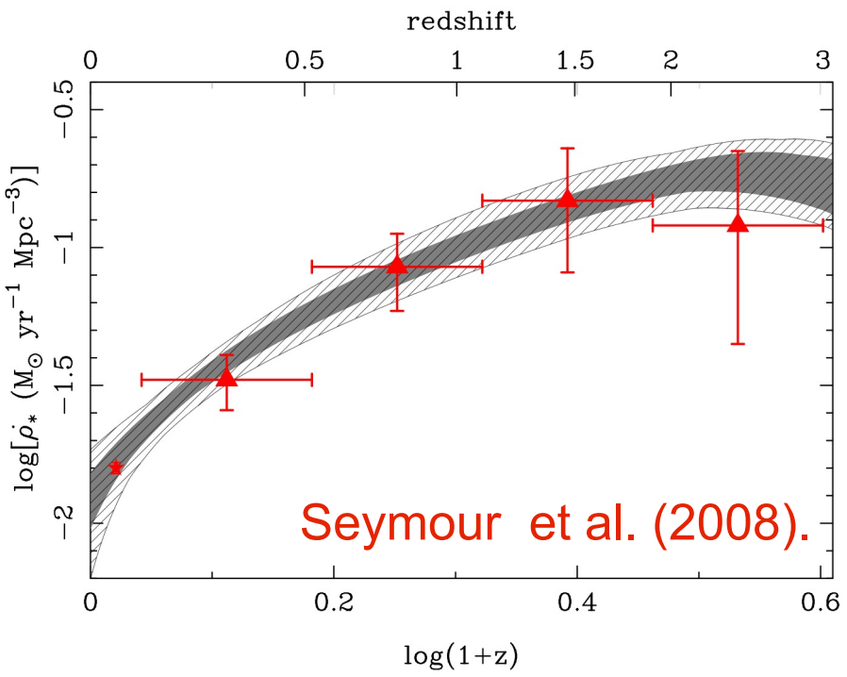
LOFAR
- high resolution
- high sensitivity

Population Studies



SFG RLF from Smolcic et al. (2009).

Radio Luminosity is a dust-free tracers of SFR.

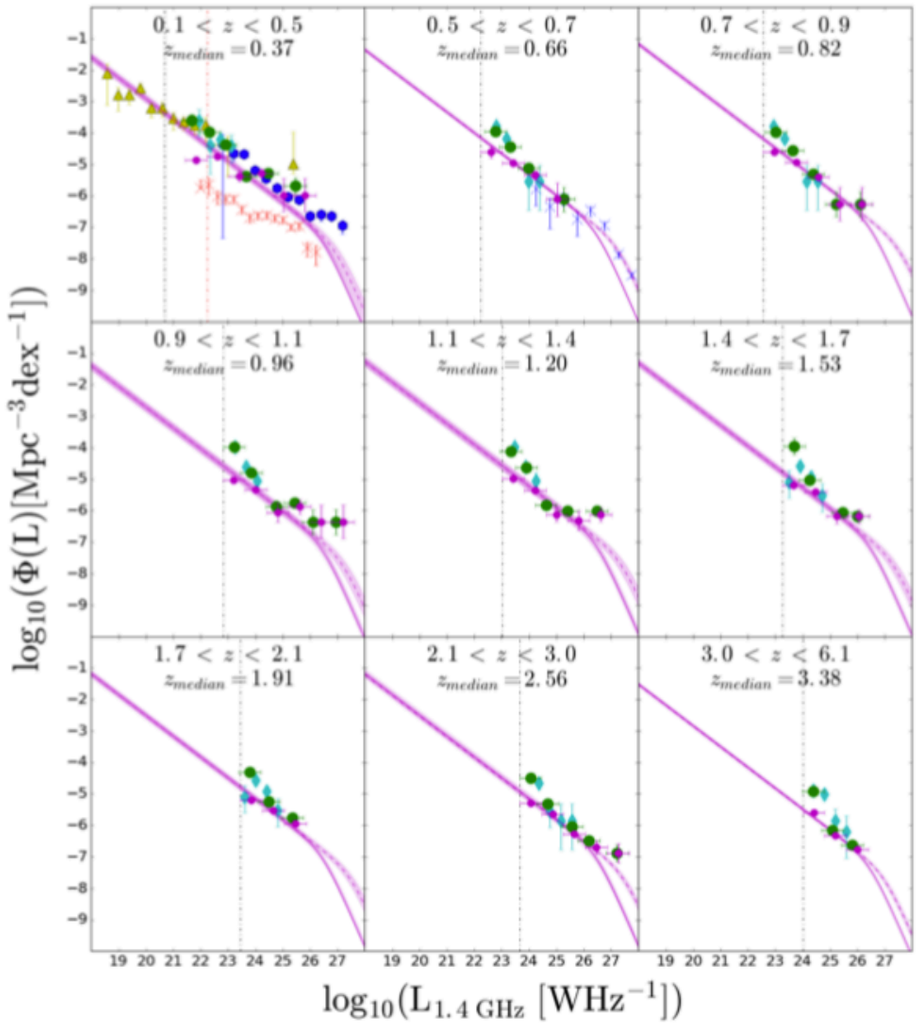


Radio-surveys trace:

- bipolar relativistic outflows (‘jets’) from supermassive black holes
- cosmic rays accelerated by supernova in star-forming galaxies

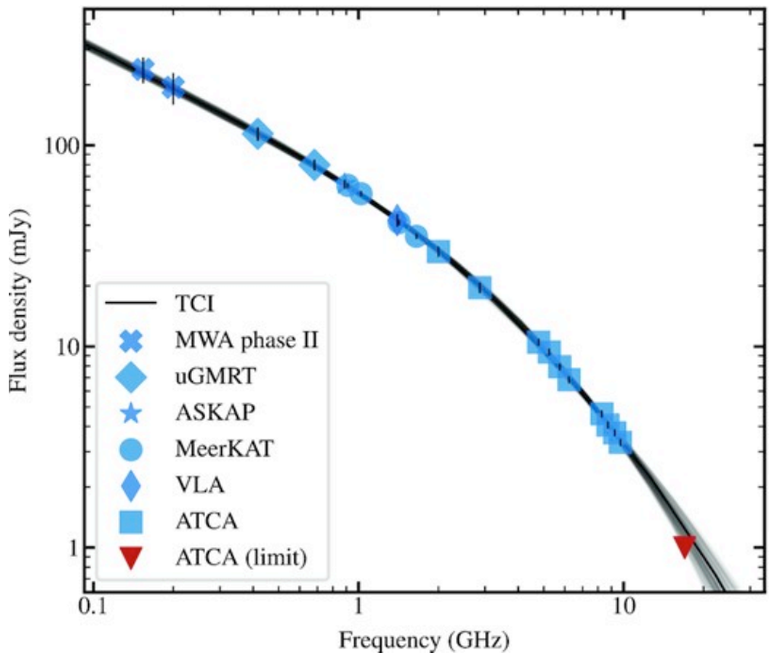
BUT!

Likewise radio-loud AGN trace cosmic history of jet power which plays a crucial role in feedback. (Ceraj et al. 2018)



Radio luminosity is not a direct tracer of jet power

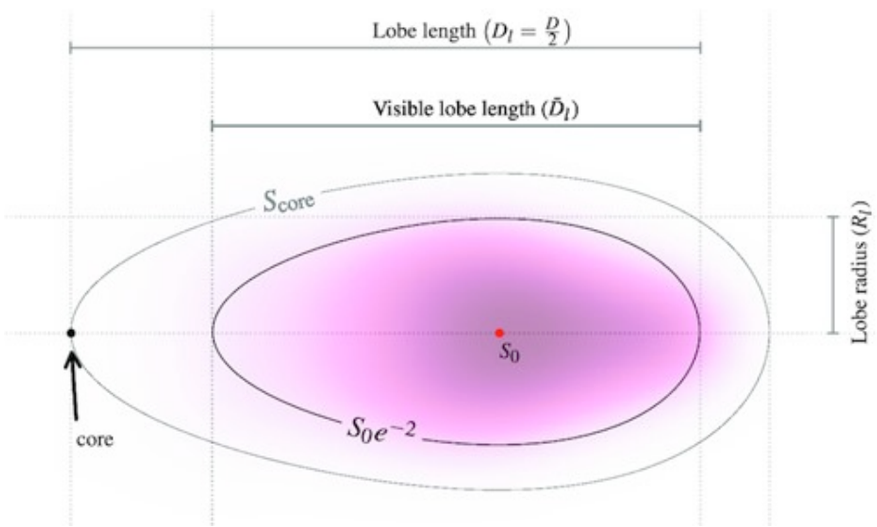
- large scatter between $L_{1.4GHz}$ and Q
- need hydrodynamical simulations
- or do you?



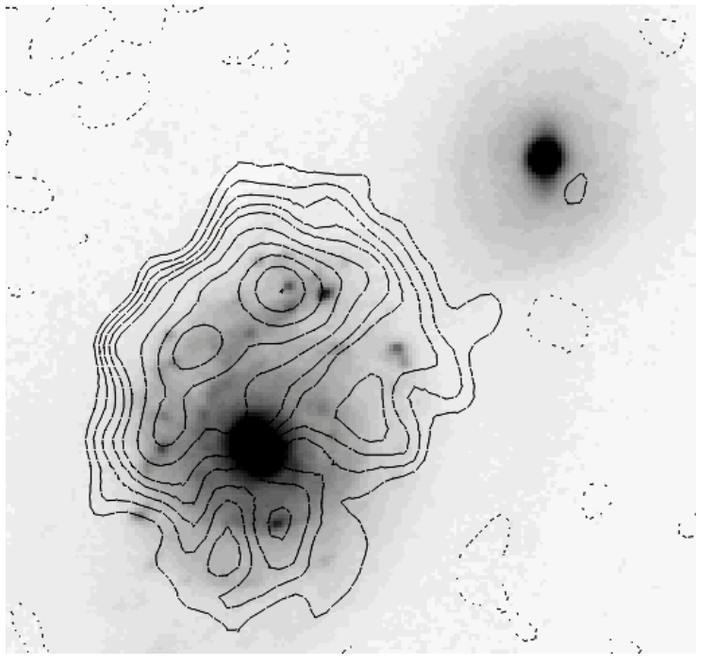
From the spectral and morphological properties, estimates of the mean jet power and age may be derived with 10% accuracy.

Energy injected into the environment= $\sum \langle Q \rangle \times t_{\rm age}$

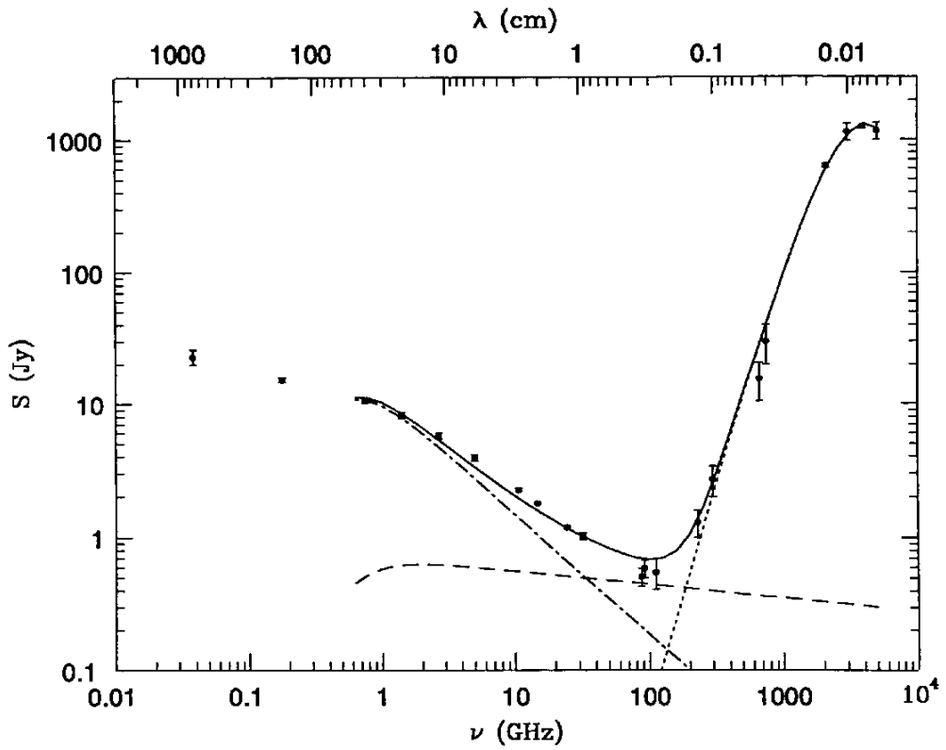
Total energy injected by jets into IGM over time



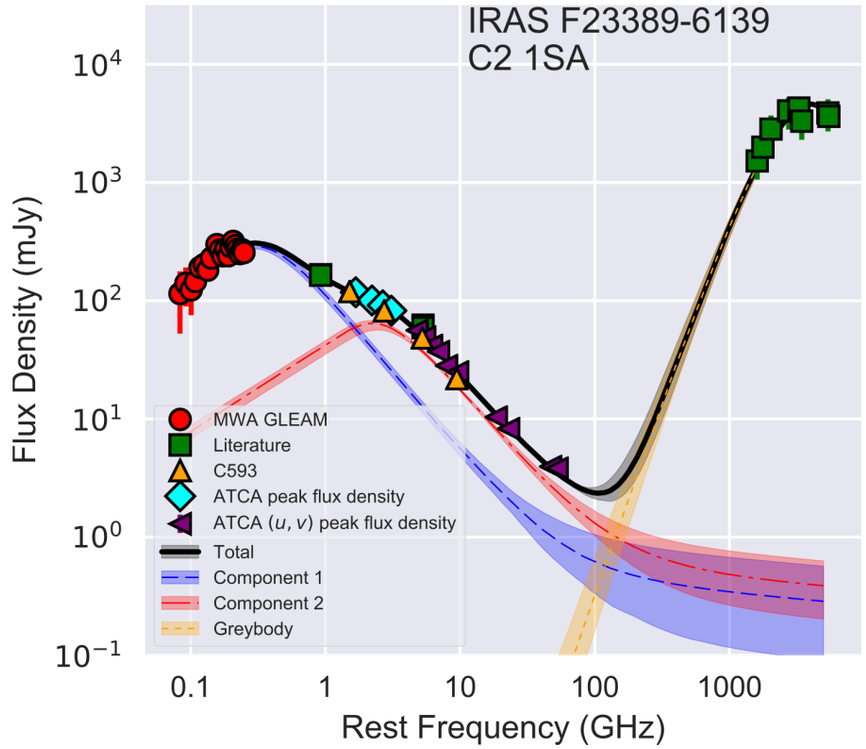
e.g. Radio AGN in Semi-analytic Environments (RAiSE; Turner & Shabala 2015) and applied by Quici et al. (2022)



Radio luminosity is not a direct tracer of star formation rate?



Radio to Far-IR spectrum of M82, Condon (1992)
3 well understood components:
- cool dust
- free-free emission
- synchrotron



Galvin et al.,(2017)
Situation becomes more complex
- turnovers
- kinks

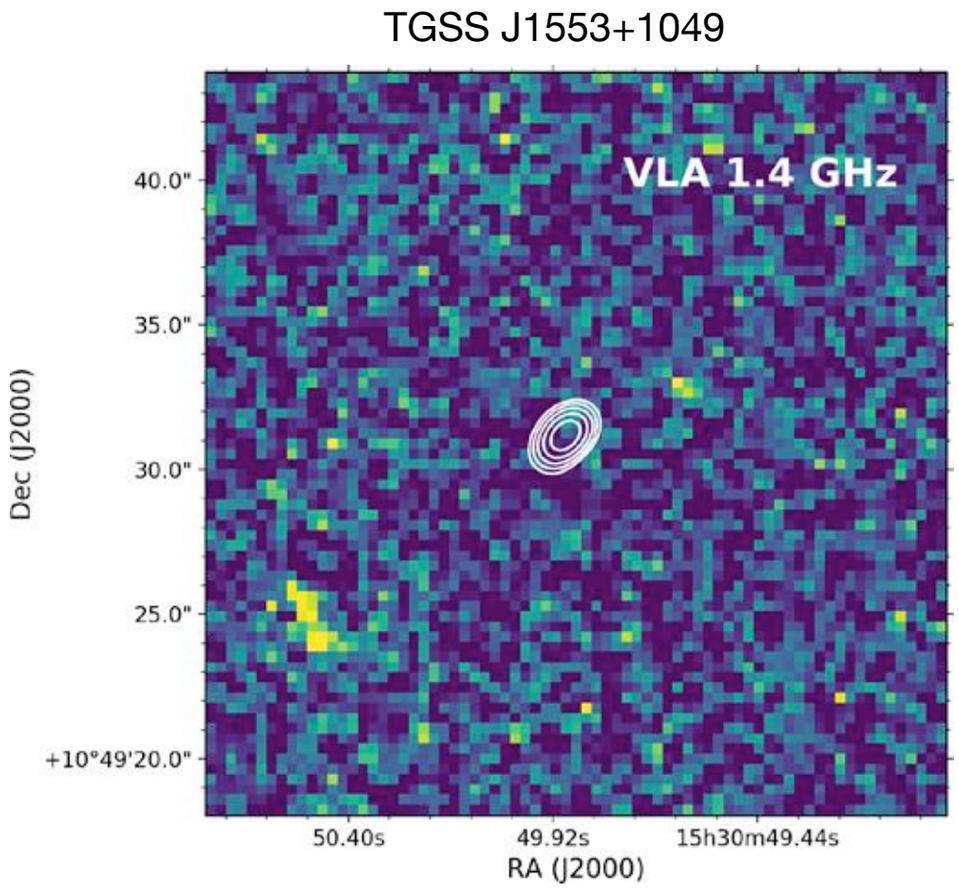
What's happening?
- morphology
- viewing angle
- timescales
- redshift
- ISM

Work on-going

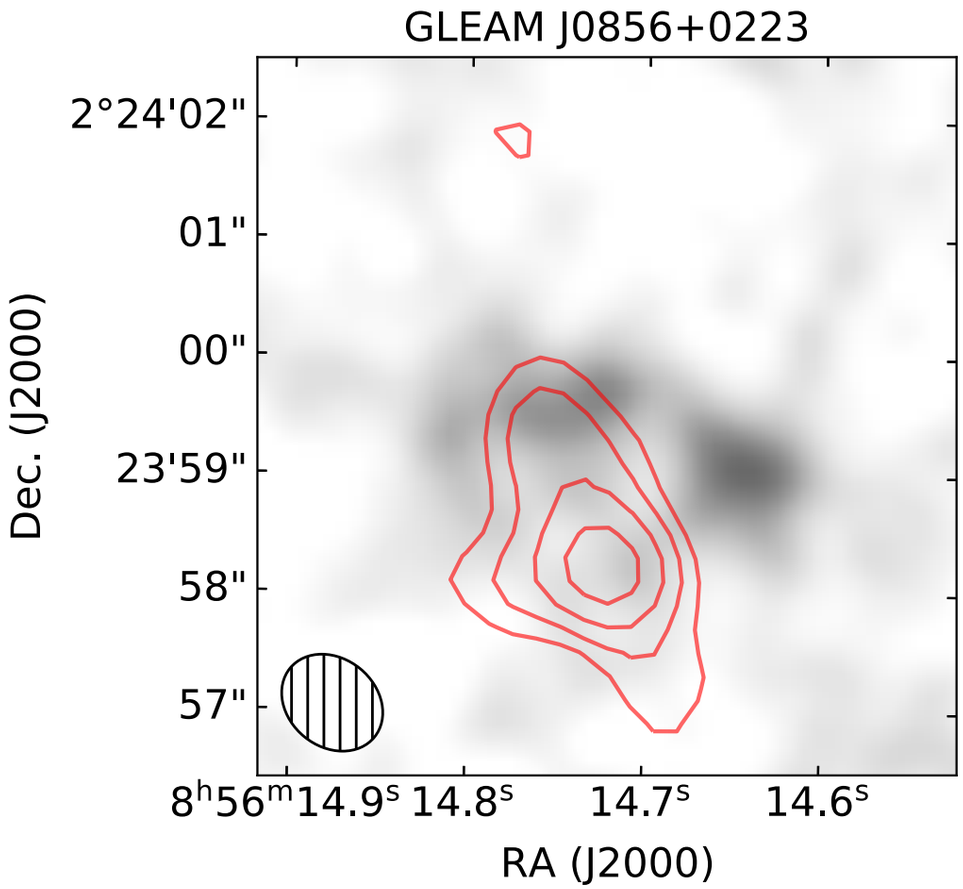
Classic view v current view

Radio sources have long been tracers of the early Universe

- e.g 3C273 (z=0.158, Schmidt, 1963) and TN J0924-221 (z=5.19, van Breugel et al., 1999)
- now low-frequency radio surveys finding new RGs at 5<z<6



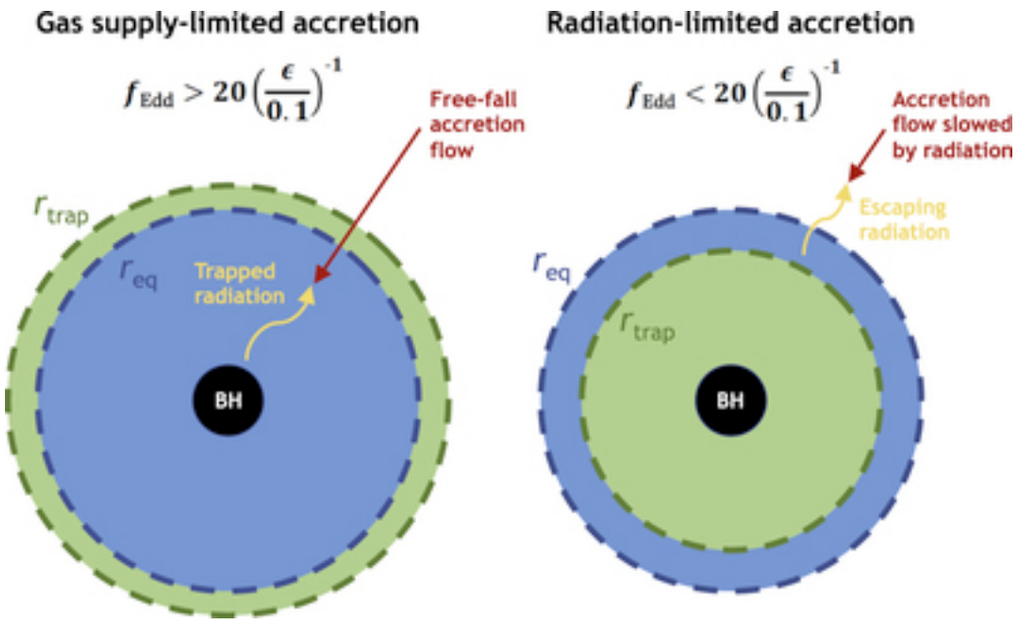
Saxena et al. (2018) z=5.72
(selected from ultra-steep spectrum)

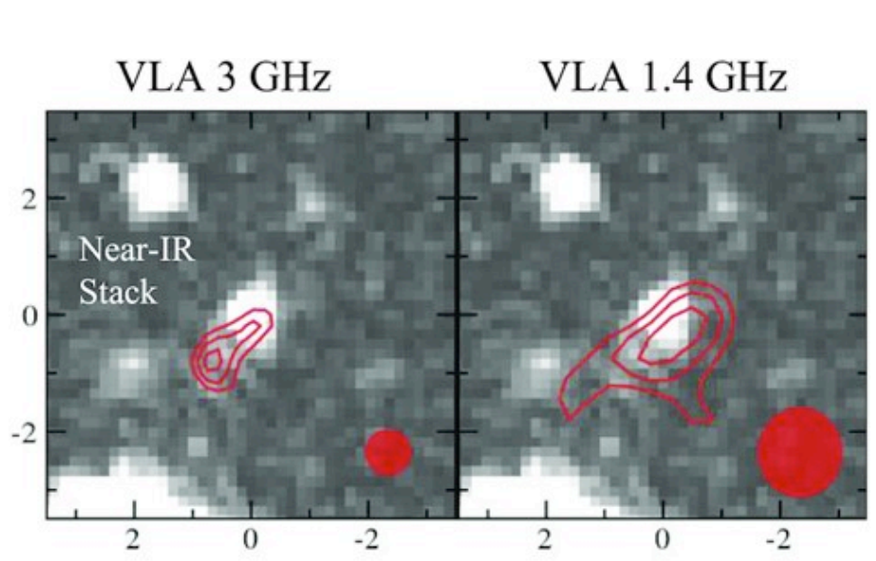


Drouart et al. (2020) z=5.55
(selected from MWA low-frequency curvature)

Many QSOs at z>6 only a few found to weakly radio-loud

- e.g VIK J2318–3113 at z=6.44 (Ighina et al. 2021)
- but likely many more obscured AGN
- with a large number of billion solar mass BHs at z~7 where are their immediate descents?
  - obscured due to very dense ISM (Gilli et al., 2022) and/or
  - obscured by super-Eddington accretion (Johnson et al., 2022)



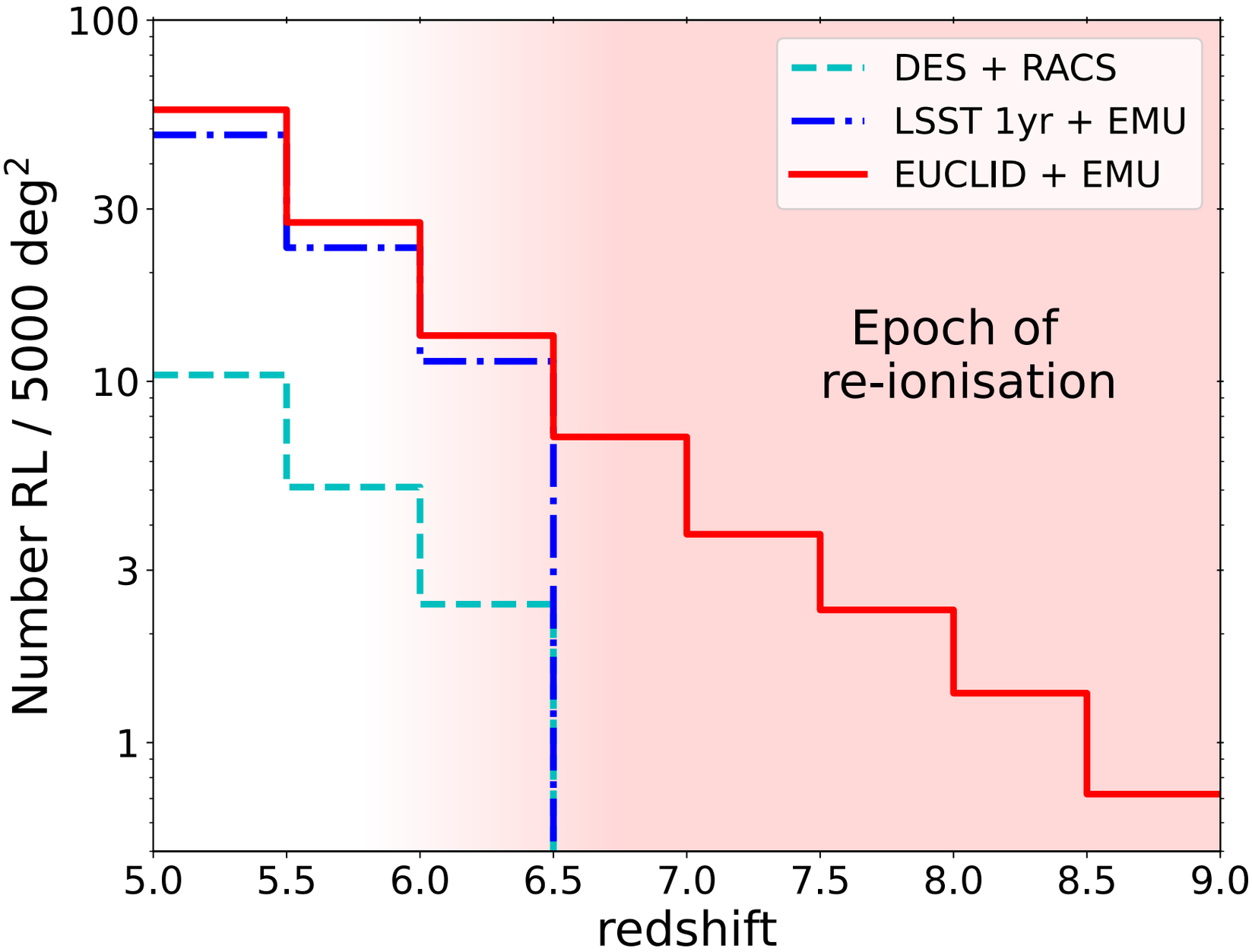


COS-87259 @z=6.83 (Endsley et al. 2022)

Could radio surveys find these obscured AGN?

Ighina et al. (in prep)

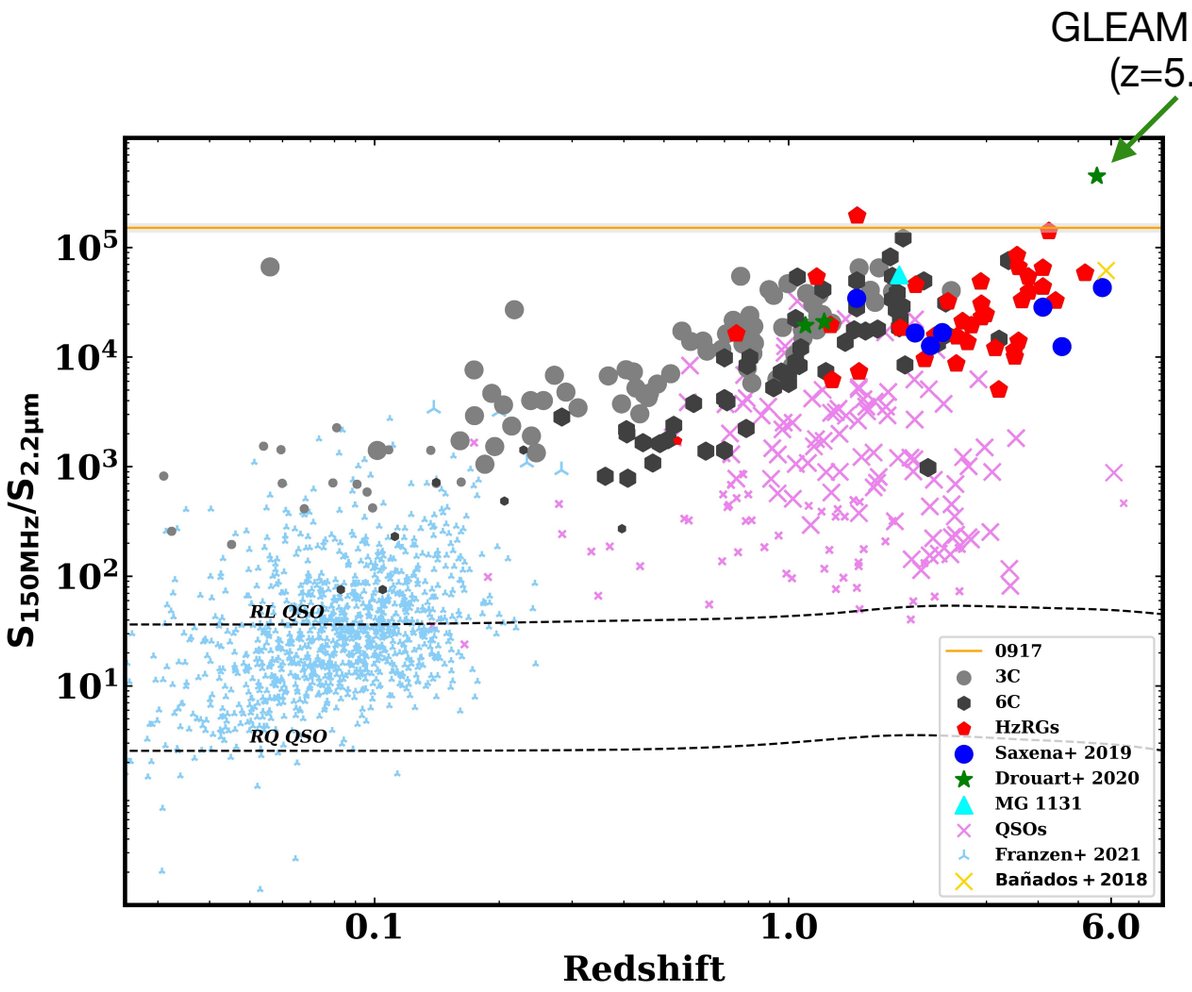
predictions at space density of RL QSOs from different surveys



with the following limits:
RACS = 1mJy
EMU = 0.1mJy
DES = 21.5mag
LSST = 23mag
EUCLID = 24.5mag

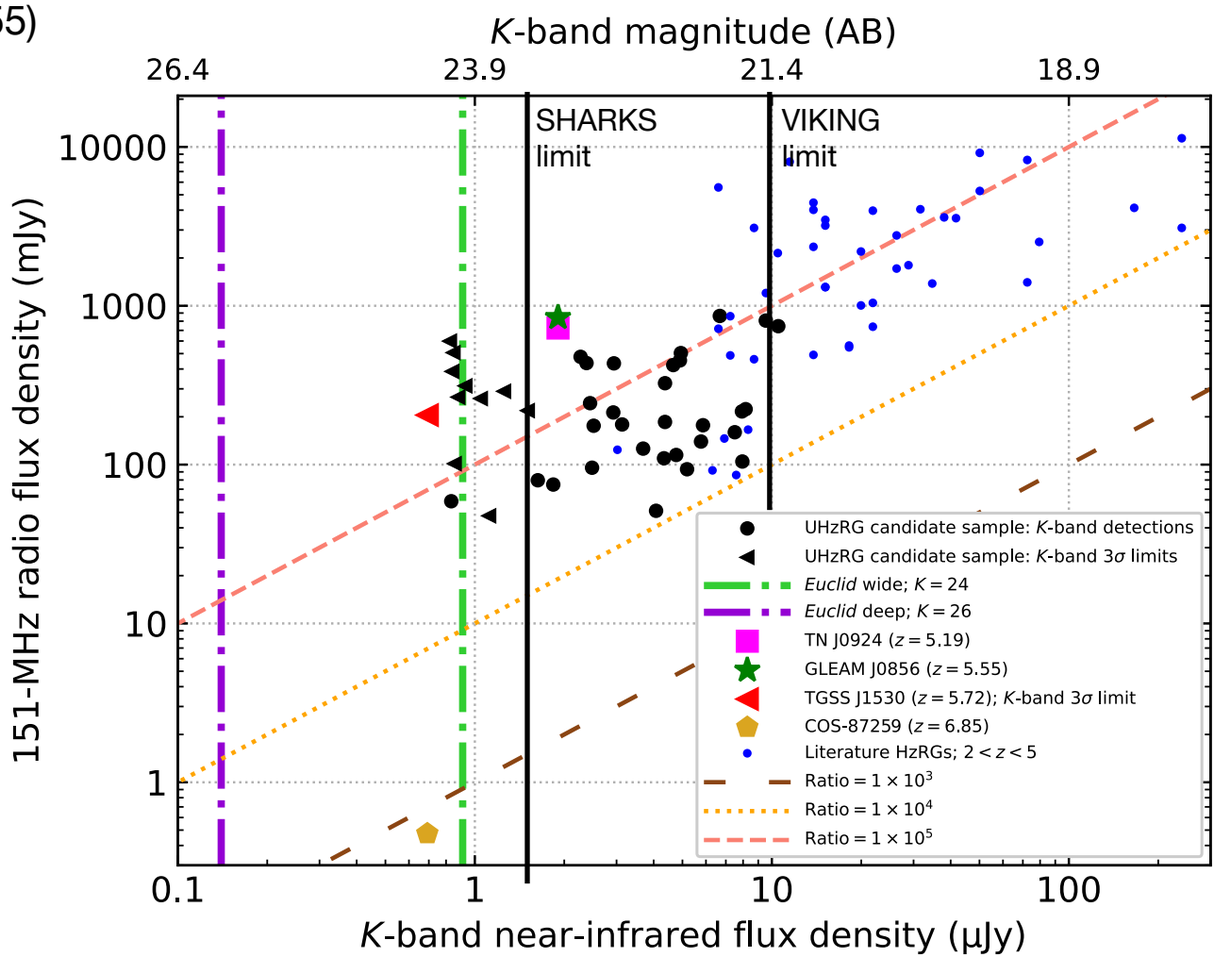
Obscured High-z Universe

Drouart et al. (2021)



Extreme low-frequency radio to K-band flux ratio favours high-z radio galaxies

Broderick et al. (in prep)

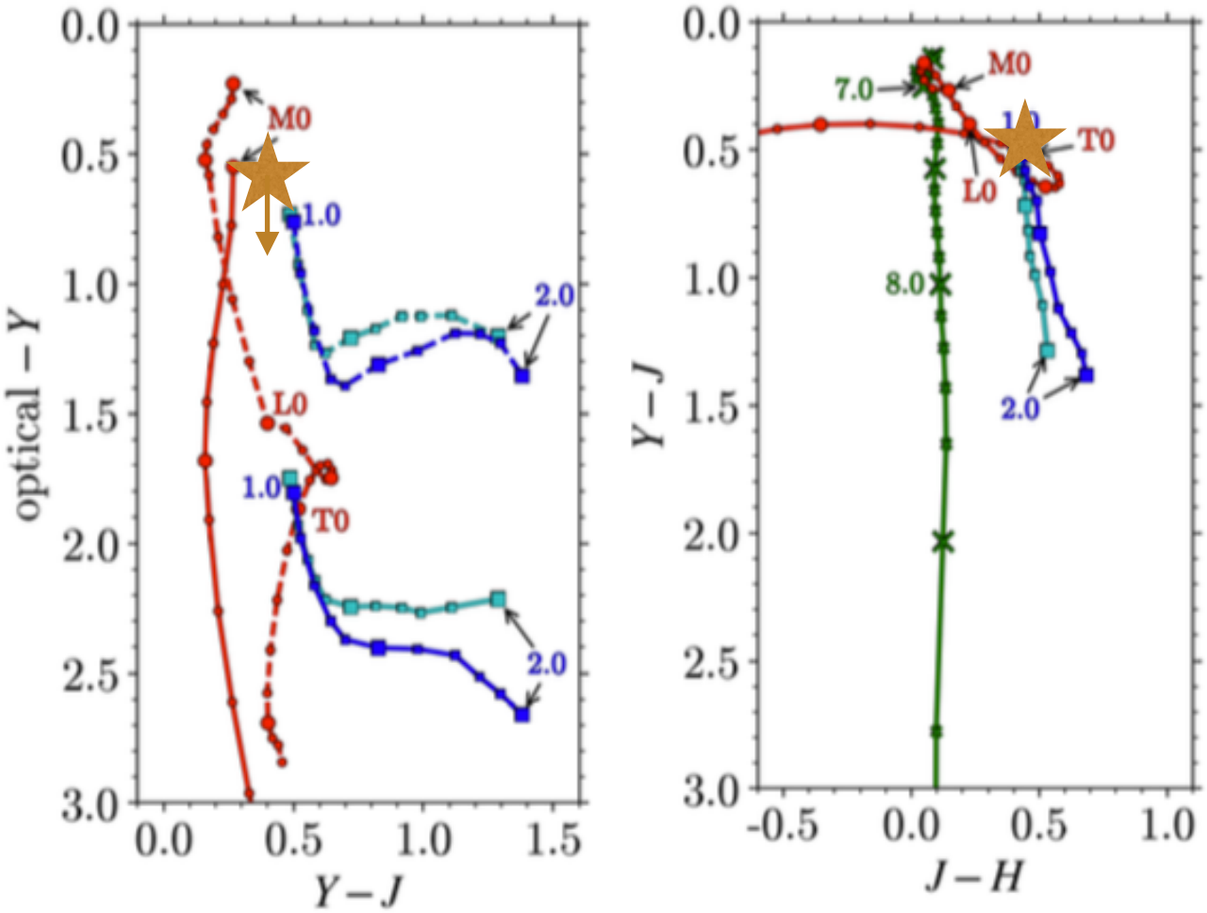


New sample of UHzRG candidates from **Broderick et al. (2022)** selected via low-frequency curvature (like GLEAM J0924). HAWKI follow-up of sample finds population of radio galaxies with hosts K<24 and radio/K flux ratio > 10^5.

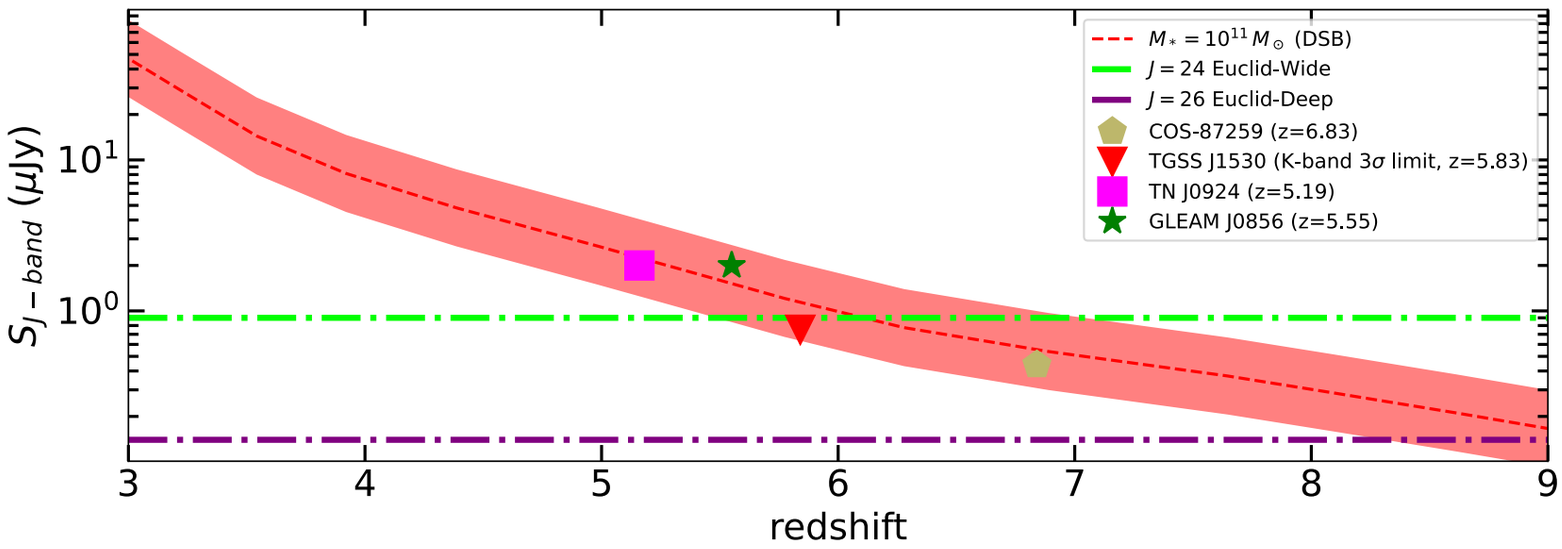
Euclid would find these easily

*I know Euclid does not cover K-band

COS-87259 ★

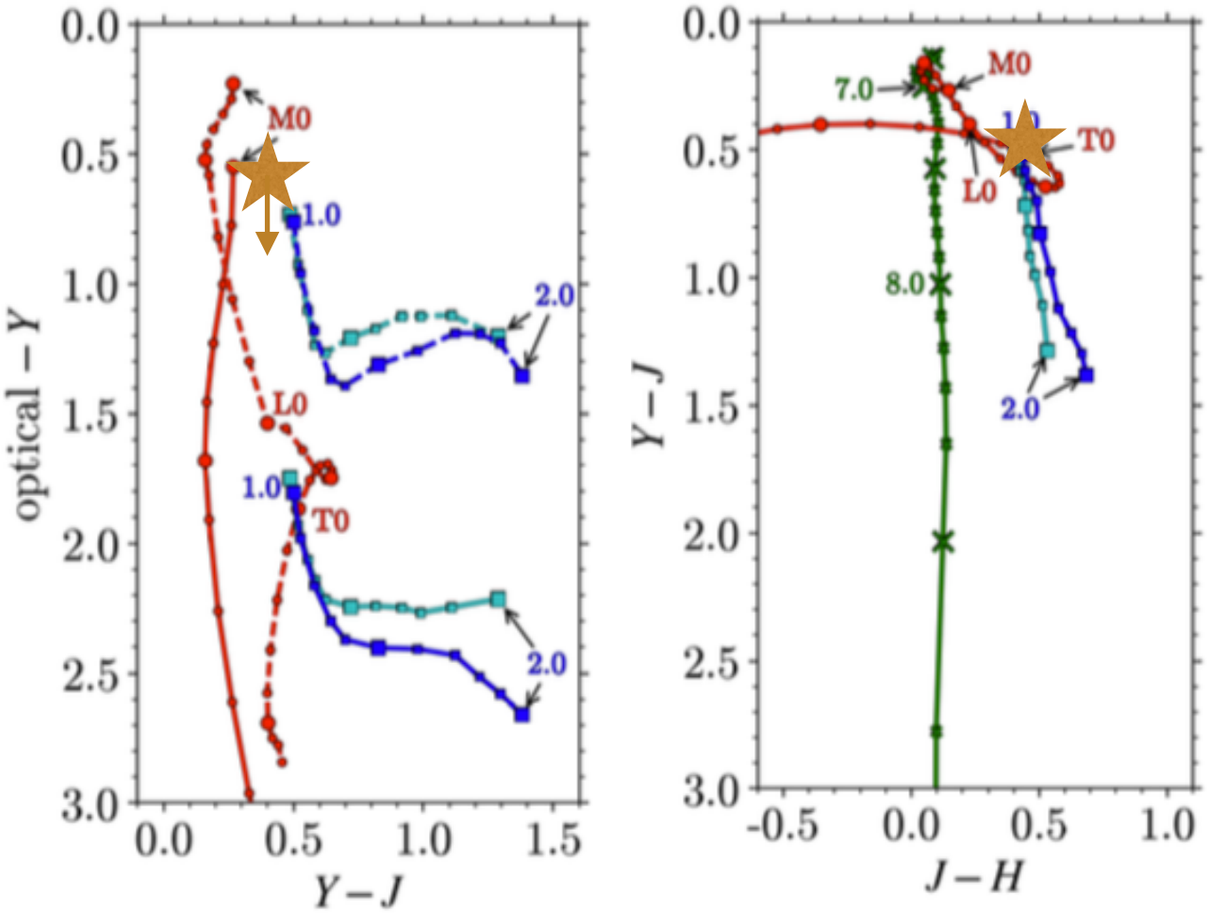


very red colours could get mixed up with LMT dwarves or z~1 dusty SFGs



K-z relation for radio galaxies continues above z=5

COS-87259 ★



very red colours could get mixed up with LMT dwarves or z~1 dusty SFGs

Unless hosts bright radio source!

Ultra-high-redshift radio galaxies find the most obscured AGN and allow:

- **studies of host galaxies**
- **studies of the impact of jets in the very Universe**
- **targets for HI absorption studies via redshifted 21-cm line**

Conclusions

- Radio surveys are powerful tools to trace star-formation and jets across cosmic time.
- Some care is needed in measuring SFR and jet powers.
- Radio sources with faint counterparts are strong candidates for the ancestors of the billion solar mass BHs at z~7
- Some interesting cosmological applications
- SKA will be a transformative facility later this decade…