The most distant radio-loud quasars

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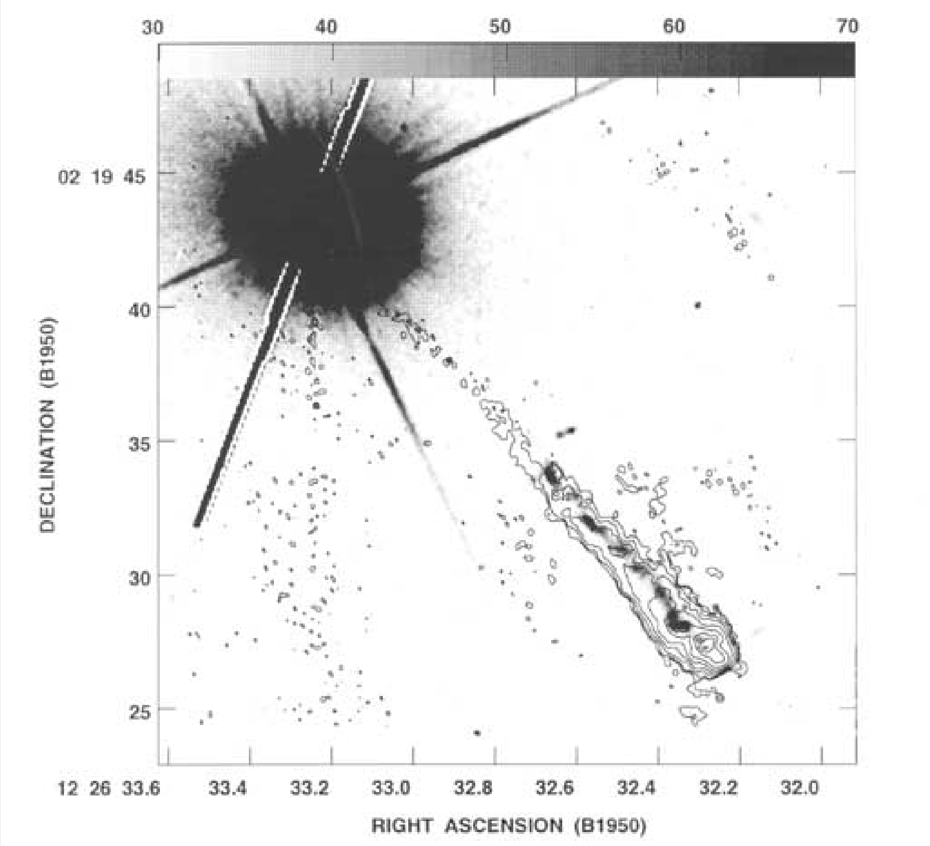
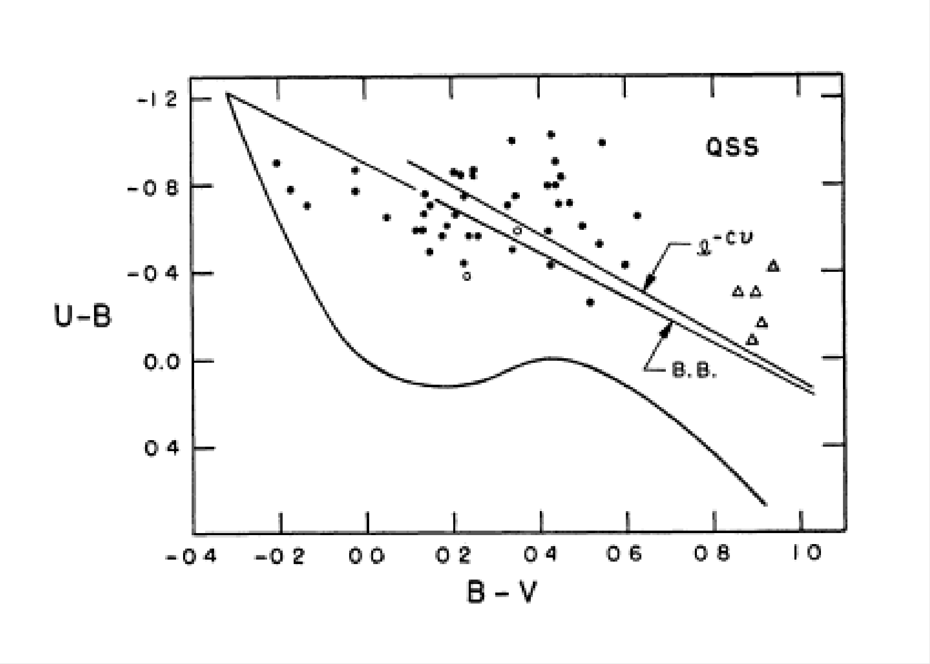
Early high-redshift quasar discoveries



- **Schmidt 1963**
  - **First quasar 3C273**
- Sandage 1965
  - UV excess method
  - “radio-quiet” quasars

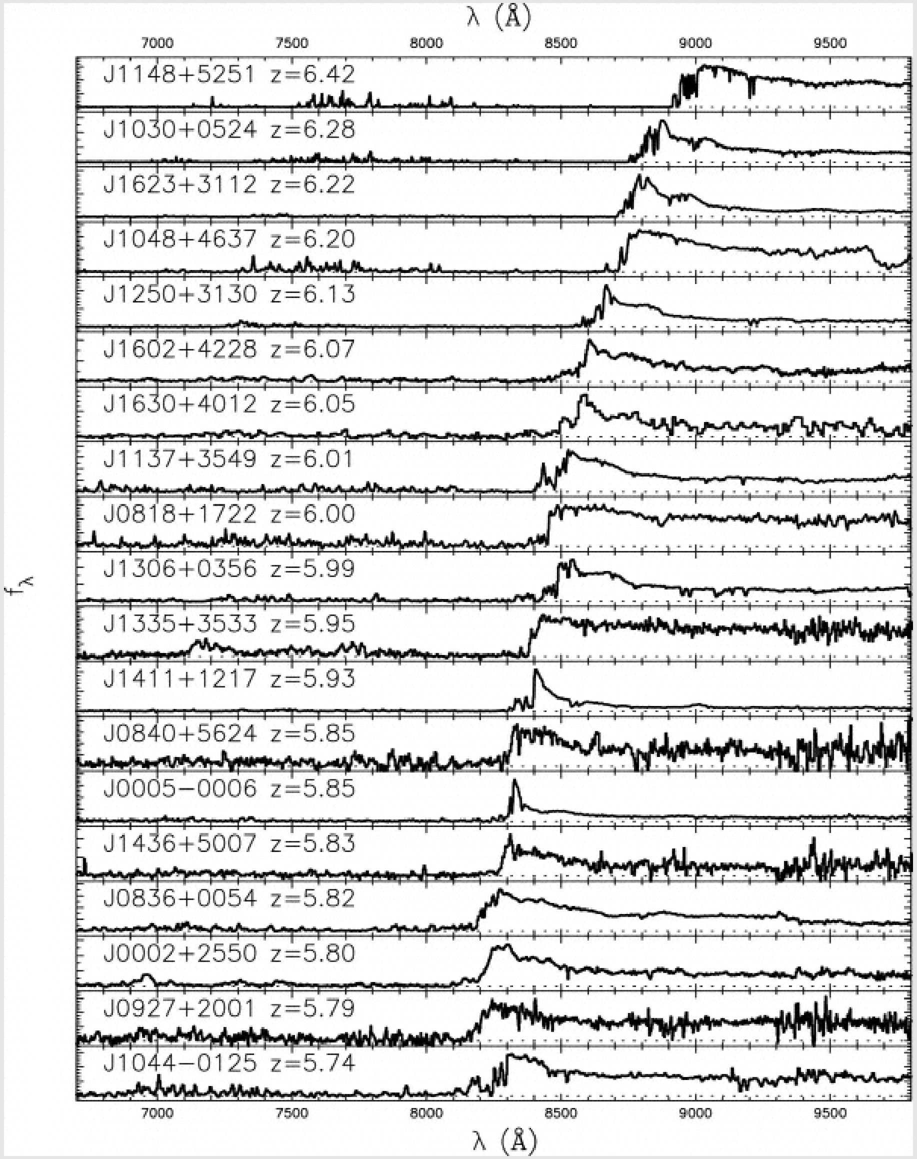
Early high-redshift quasar discoveries



- Schmidt 1963
  - First quasar 3C273
- **Sandage 1965**
  - **UV excess method**
  - **"radio-quiet" quasars**

z>6 quasars since 2000

- SDSS Main Survey (Fan et al. 2001-06)
  - ~7000 sq. deg.
  - $z_{AB} < 20.2$
  - **9 z>6 QSOs**
- SDSS Southern Stripe (Jiang et al. 2008)
  - 260 sq. deg.
  - $z_{AB} < 21.0$
  - **4 z>6 QSOs**
- Canada-France High-z QSO Survey (Willot et al. 2007)
  - ~400 sq. deg.
  - $z_{AB} < 22.5$
  - **4 z>6 QSOs**



Fan et al. (2006)

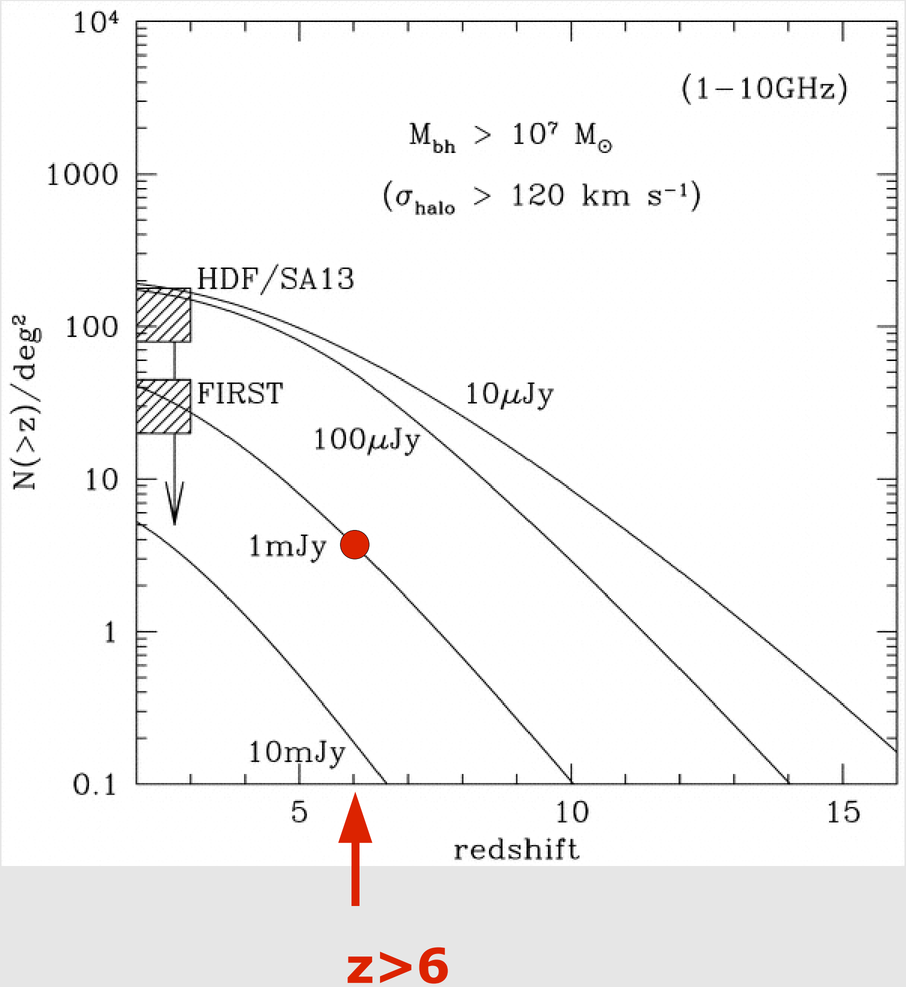
Predictions for radio source counts

Haiman, Quataert, & Bower 2004

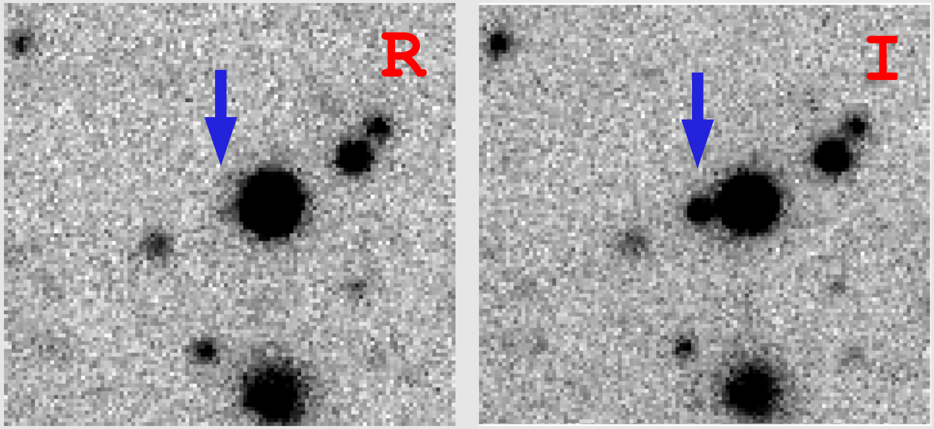
semi-analytic model:

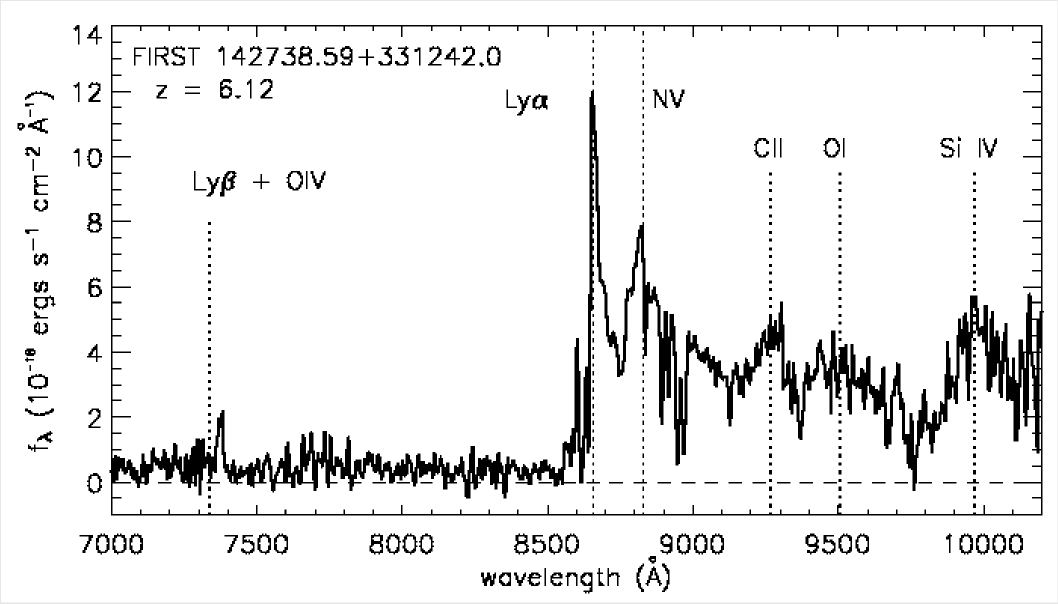
1) DM halo growth by mergers
2) M-σ relation gives central BH mass
3) 10% radio-loud fraction
4) quasar duty cycle of 10^7 years

predicts several z>6 quasars per square degree in the FIRST survey!



Discovery of z=6.1 Radio-Loud Quasar in the NDWFS



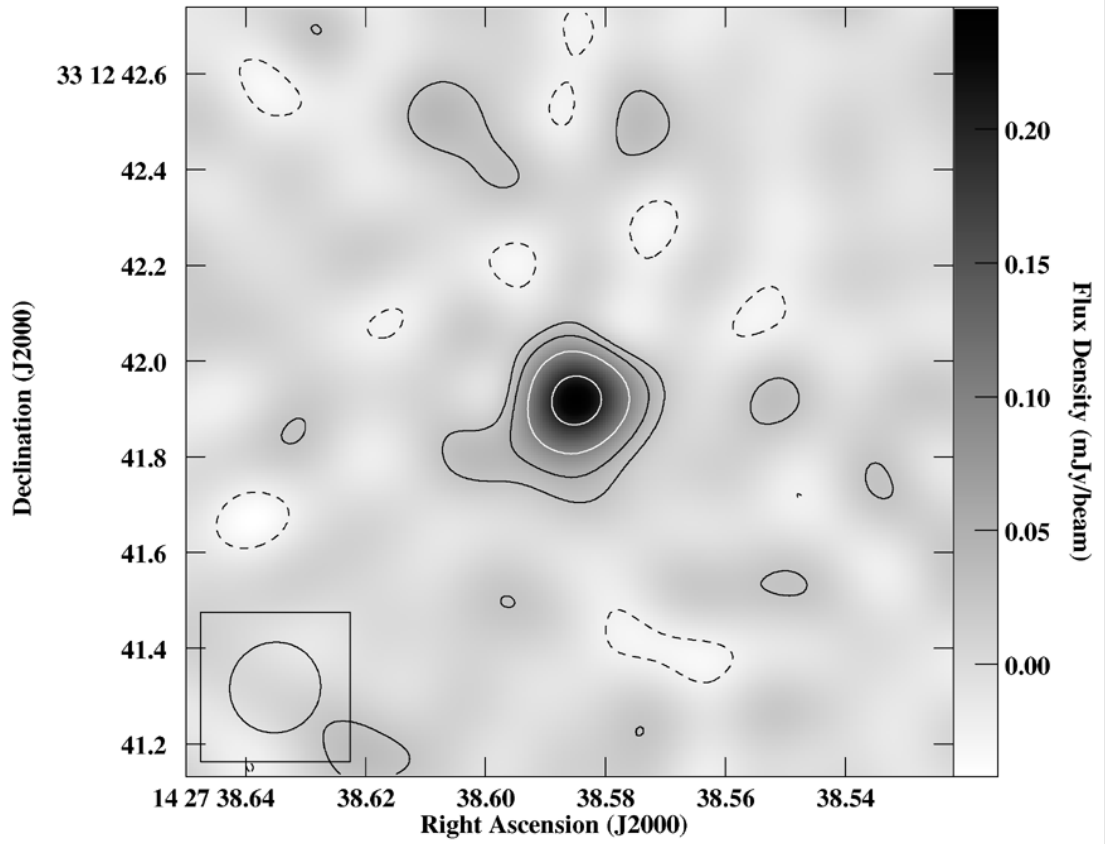


- Optical/IR identification of radio sources in **4 deg²** Boötes region
  - NDWFS (I < 25)
  - FLAMEX (K_s < 19.5)
  - FIRST ($S_{1.4}$ > 1 mJy)
- One z>6 candidate, Keck spectroscopy confirmed z=6.12
- Strong BAL features
- red color z-J > 2.2
  - SDSS z>6 quasars have z-J < 1.5

(IM, Becker, Helfand, & White 2006)

VLA/VLBA observations of J1427+3312

VLA-A 8GHz **250 μJy**

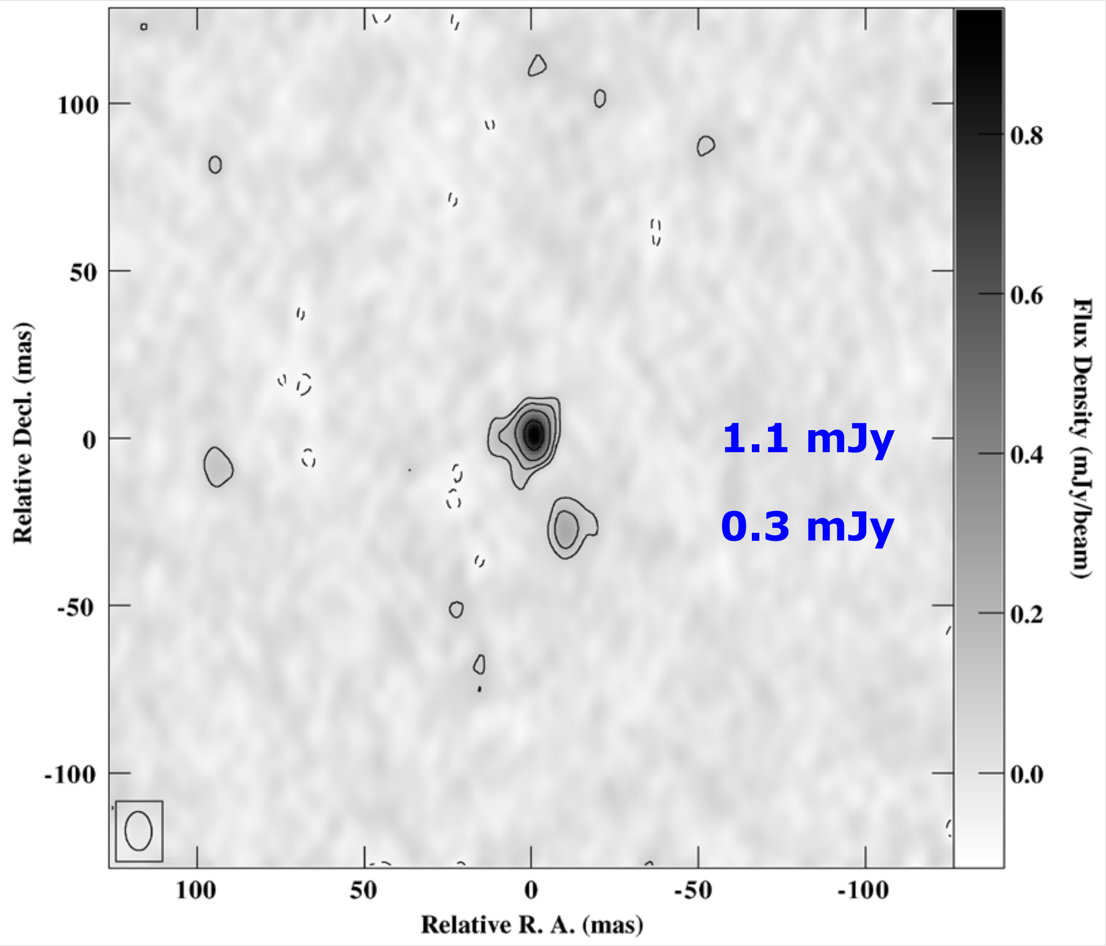


Momjian, Carilli, & IM (2008)

- no ≤ 1'' lensing
- steep spectrum
  - $\alpha = -1.1$

VLA/VLBA observations of J1427+3312

VLBA 1.4GHz



Momjian, Carilli, & IM (2008)

- no ≤ 1'' lensing
- steep spectrum
  - α = -1.1
- Compact Symmetric Object
  - physical scale ~170pc
  - t ~ 1000 years

see poster by S. Frey

How can we find more high-z quasars?

optical – contamination from stars, only to $z < 6.5$

infrared – contamination from galaxies ($z\sim3$, Smail et al. 2008) and stars ($z\sim6$, Glikman et al. 2008)

radio?

FIRST/SDSS "colorblind" quasar selection

efficient selection of high-z quasars
by combining SDSS and FIRST

- FIRST/SDSS match < 0.5''
  - *minimal stellar contamination*
- $u - g > 1.5$, $g - r > 0.7$
  - *red colors, $z > 3.5$*

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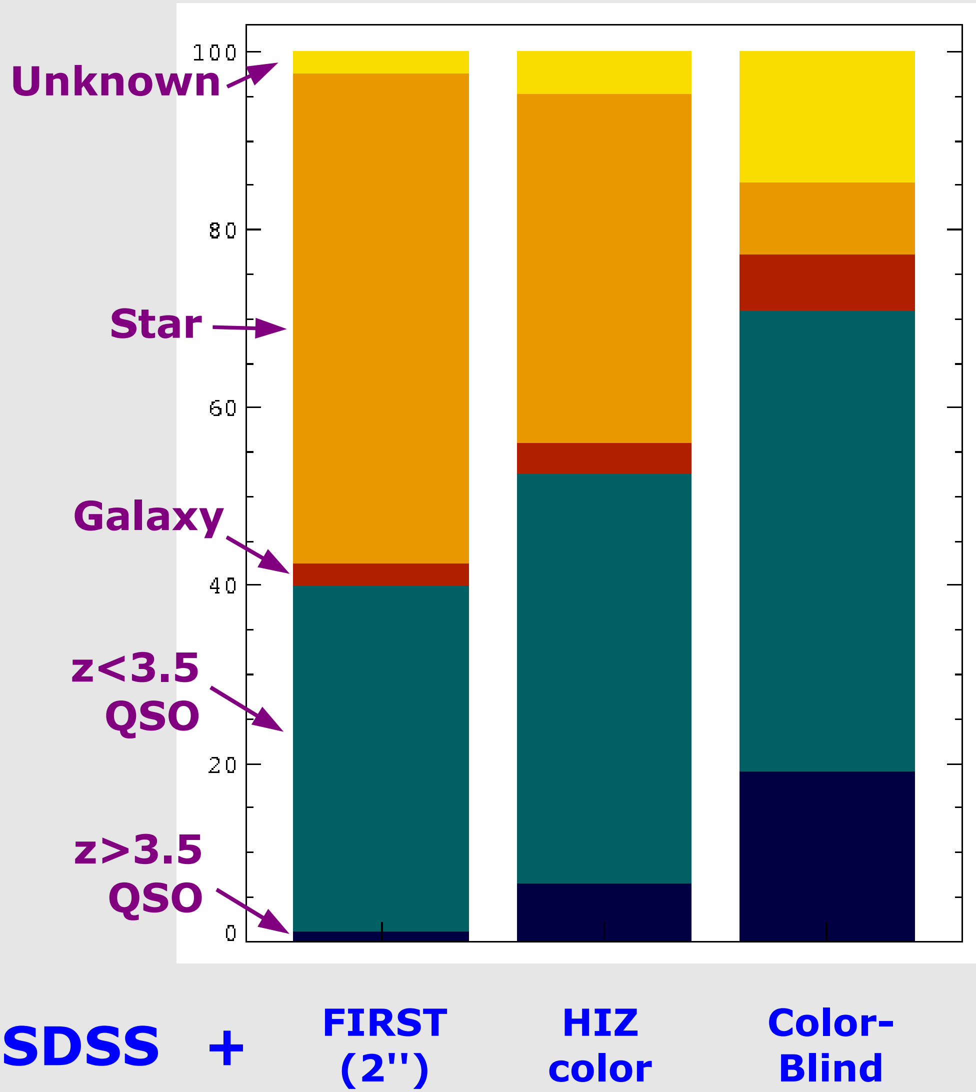
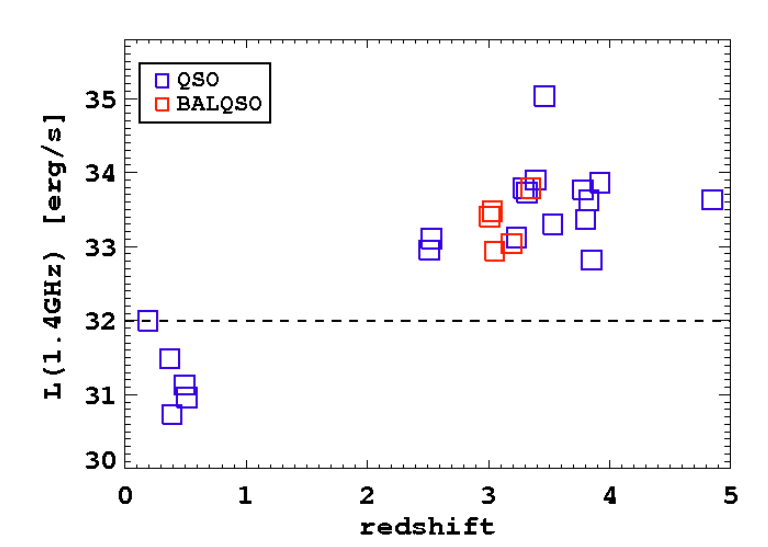


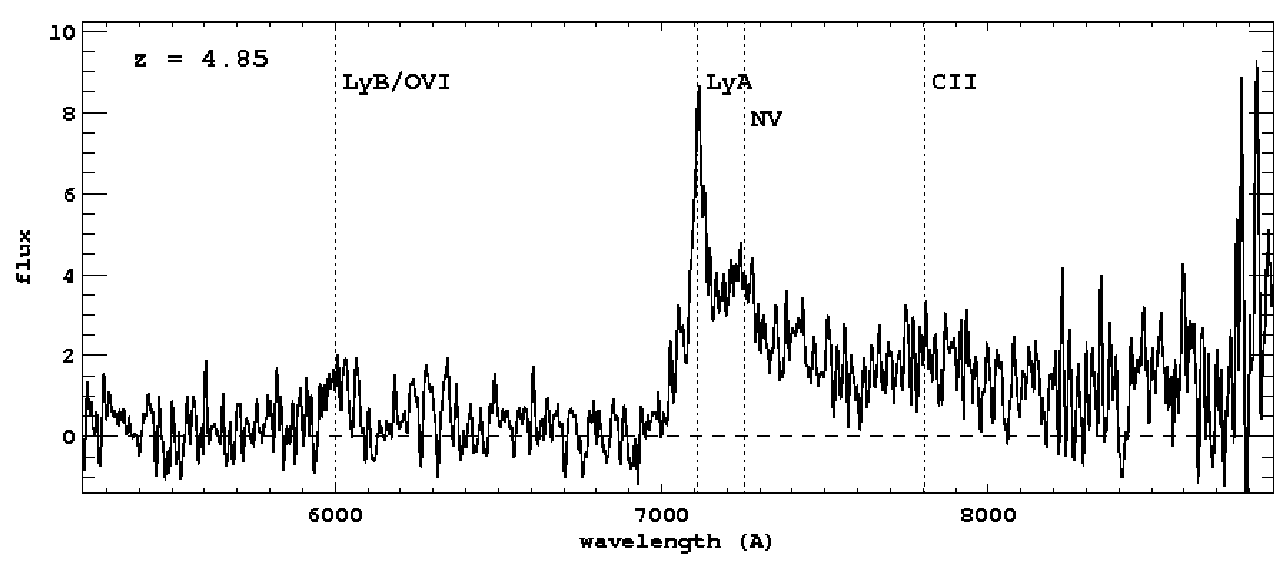
MDM observations (June 2008)

2.4m Hiltner

~50 spectra   18.5 < i < 20

new QSOs:	24
z>3 QSOs:	17
z>3.5 QSOs:	8
BALQSOs:	5





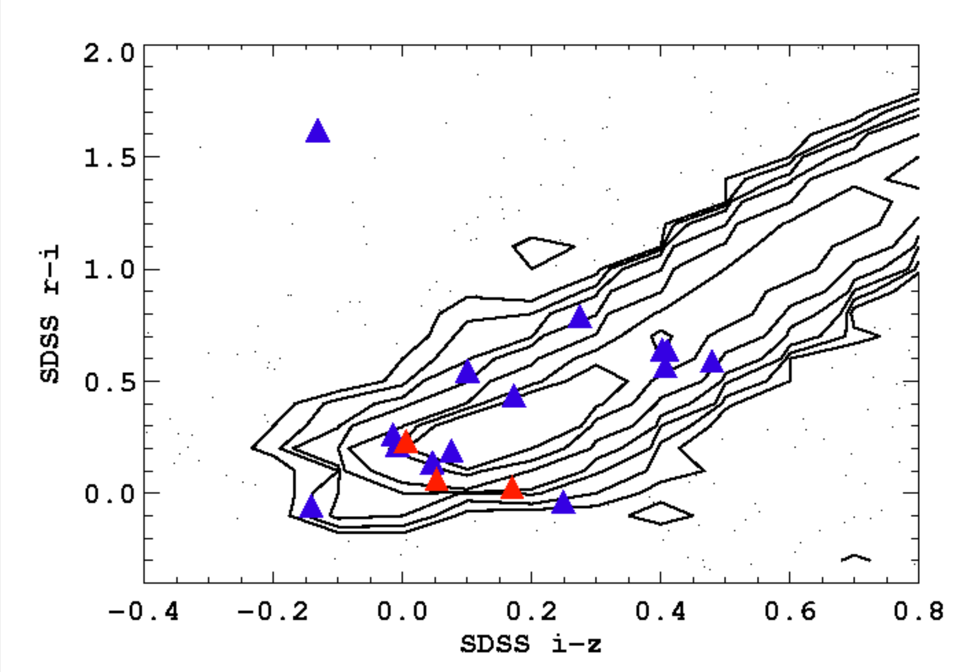
8th most distant RLQSO (z=4.85, g-dropout)

reduction in progress!

SDSS QSO incompleteness at z > 3

Only ~10% of ColorBlind candidates were targeted by SDSS

SDSS is reported to be 75-90% complete at z>3, but only 3/17 ColorBlind z>3 QSOs were targeted



stars vs. quasars...

Do radio-loud quasars decline at high-z?

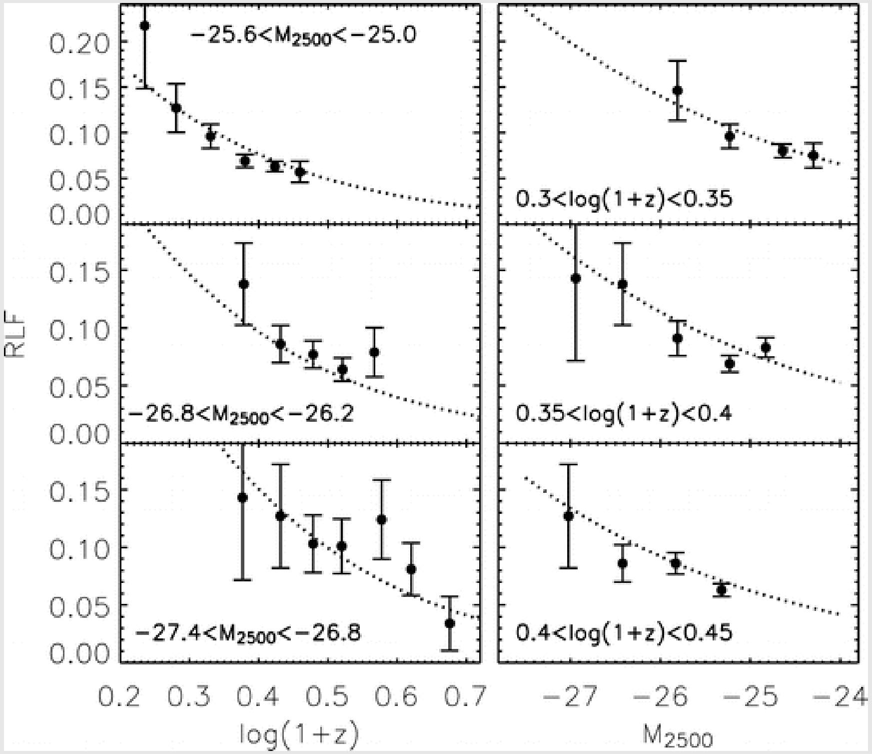
Jiang et al. 2007

R = F(5GHz) / F(2500A)

~40,000 quasars from SDSS DR3 matched to FIRST

Radio-Loud Fraction (RLF) decreases with luminosity and redshift

From ~25% at z=0.5 to 4% at z=3



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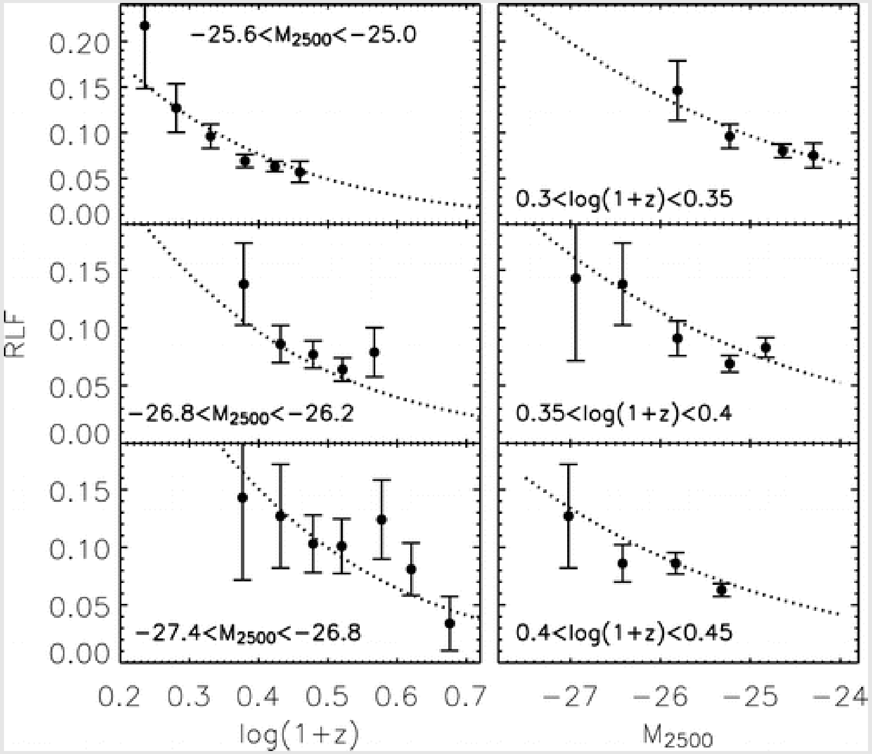
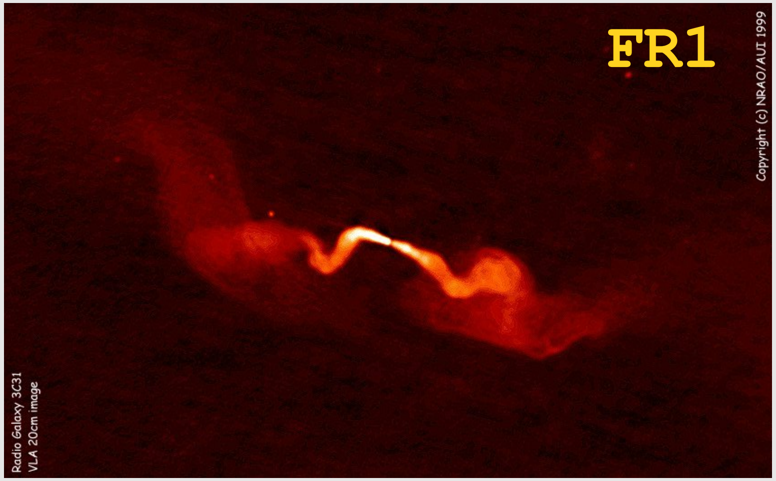
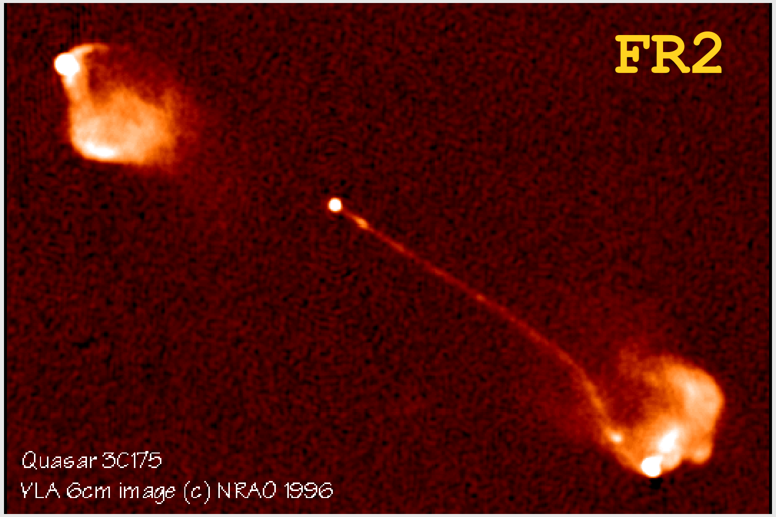


However, selection effects...

Radio galaxy properties





Fanaroff-Riley 1974

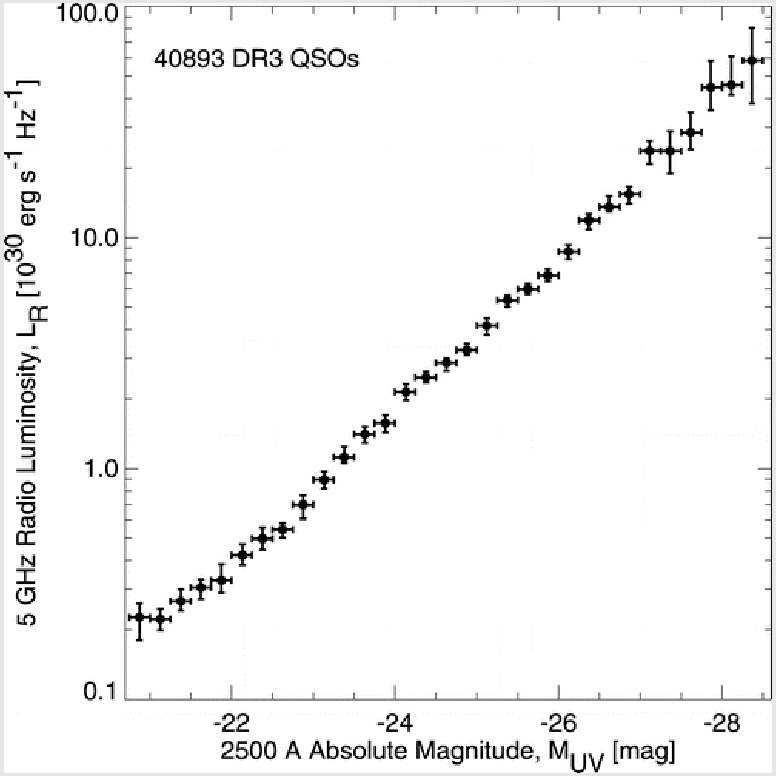
dichotomy of radio galaxy properties – morphology and luminosity

unification – RLQSOs are FR2s

Radio quasars and red quasars

White et al. 2007
Image stacking of SDSS quasars

Radio emission is strongly correlated to optical luminosity...



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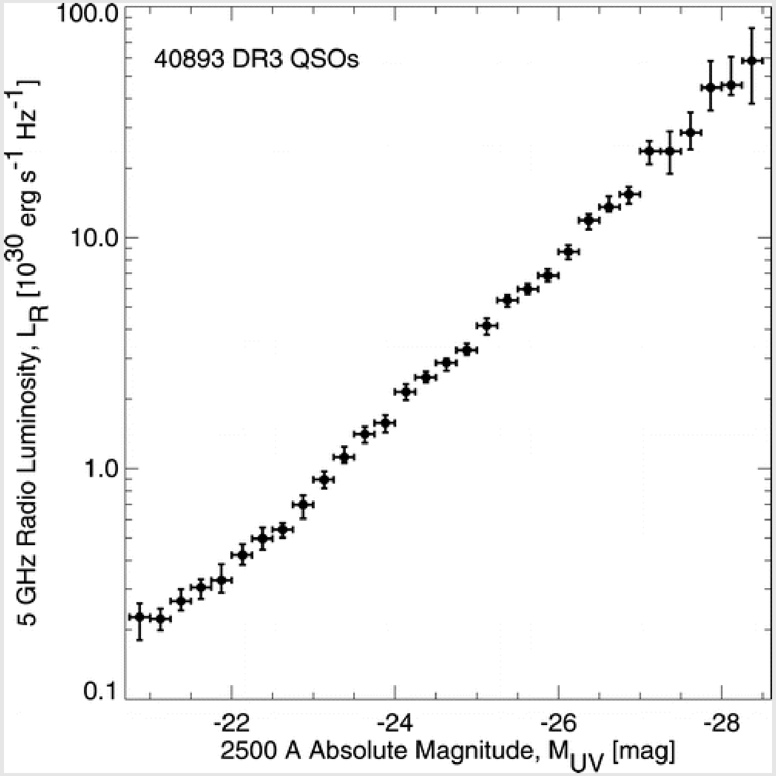
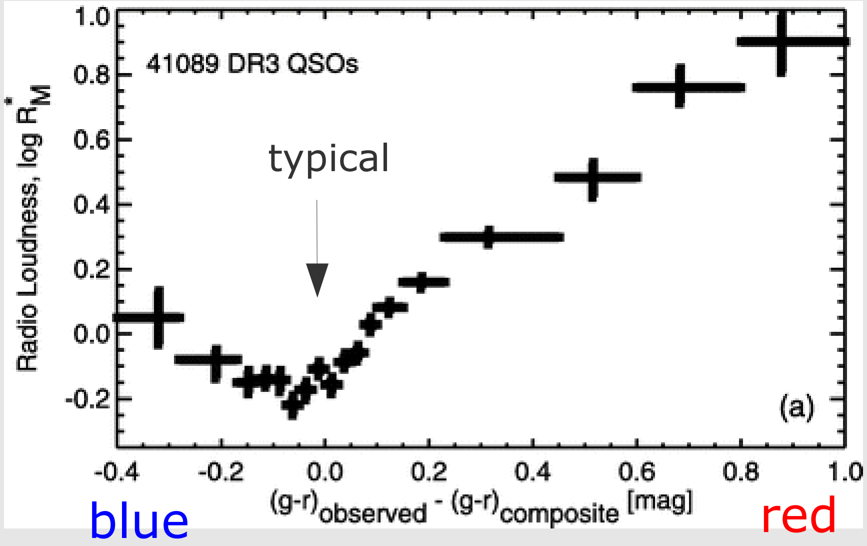




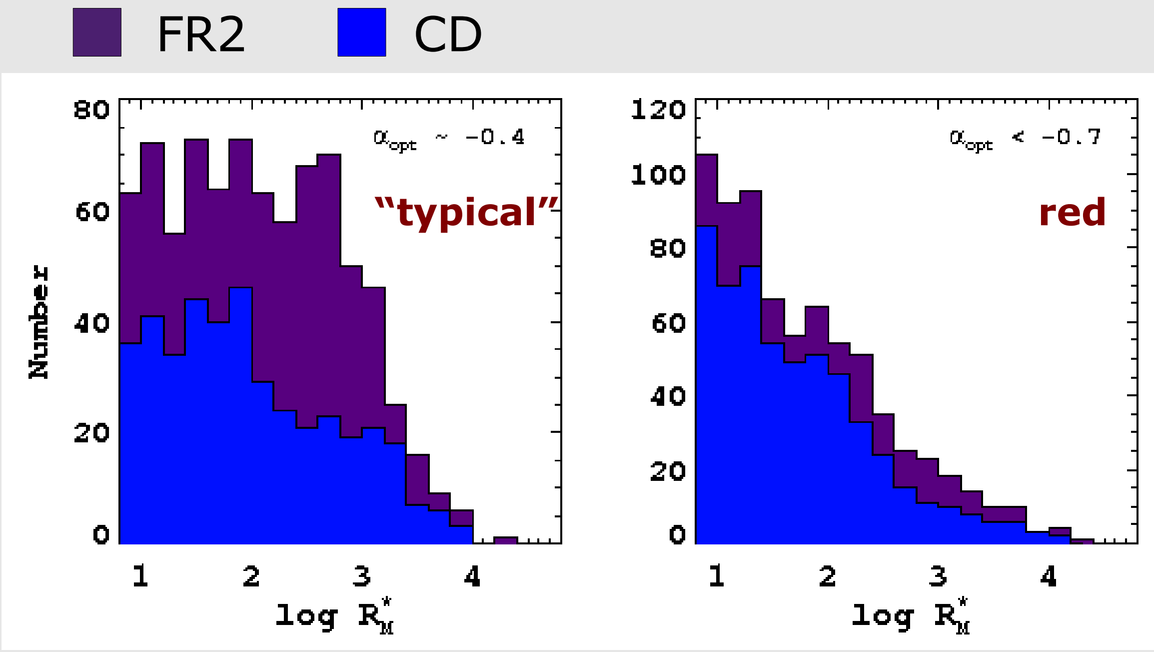
... but is stronger in red QSOs

Radio quasars and red quasars

SDSS DR5 QSOs

"Typical" QSOs have both FR2 and CD (core-dominated) radio counterparts

Red QSOs are almost all CDs, and increase in number to the FIRST limit



Conclusions and future prospects

- Radio emission is an ubiquitous quasar phenomenon
- Selection highly reliable and unbiased in color
- Serendipitous discoveries
- Radio traces the significant population of red quasars
- High-z RLF still uncertain

- LOFAR, EVLA, ...
  - low frequencies closer to emission peak
- 21cm absorption studies at EoR (Carilli et al. 2002)
  - >80% of CSOs show 21cm absorption