Radio luminosity function below the detection threshold

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SPARCS

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RESPICE PROSPICE

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SKA AFRICA
SQUARE KILOMETRE ARRAY

Radio luminosity functions

- Luminosity function is the number of sources in a luminosity interval over a given volume.
- Luminosity being intrinsic can give clues about the nature of the sources.
- We use the radio luminosity function to:
  - Probe the nature of radio emission from radio quiet quasars.
  - Study the cosmic star-formation history.
- All the previous generation of large radio surveys have detections above 1mJy at 1.4 GHz, where radio-quiet quasars and star-forming galaxies start to dominate.

Bayesian stacking

- Need axillary data (e.g optical).
- Extract radio flux at axillary position.
- Bin the sources [S_{mi} ,S_mi+ Δs_{mi}].
- Assuming the number of sources in the flux bin follows a Poisson distribution then the likelihood is,

$$\mathcal{L}_i\left(k_i|\boldsymbol{\theta}\right) = \frac{I_i^{k_i}\mathrm{e}^{-I_i}}{k_i!},$$

$$I_i = \int_{S_{min}}^{S_{max}} \mathrm{d}S \frac{\mathrm{d}N(S)}{\mathrm{d}S} \int_{S_{m_i}}^{S_{m_i}+\Delta S_{m_i}} \mathrm{d}S_m \frac{1}{\sigma_n\sqrt{2\pi}} \mathrm{e}^{-\frac{(S-S_m)^2}{2\sigma_n^2}}.$$

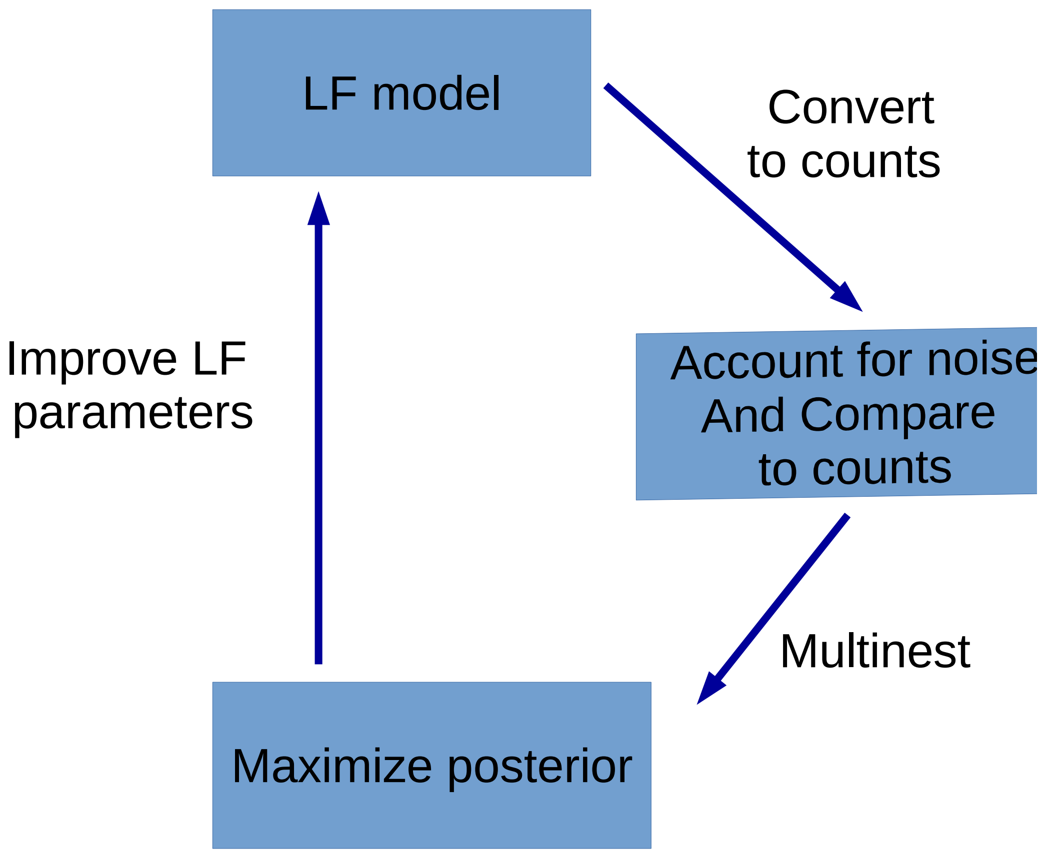
$$\mathcal{P}\left(\boldsymbol{\Theta}|\mathbf{D},H\right) = \frac{\mathcal{L}\left(\mathbf{D}|\boldsymbol{\Theta},H\right)\Pi\left(\boldsymbol{\Theta}|H\right)}{\mathcal{Z}\left(\mathbf{D}|H\right)}.$$

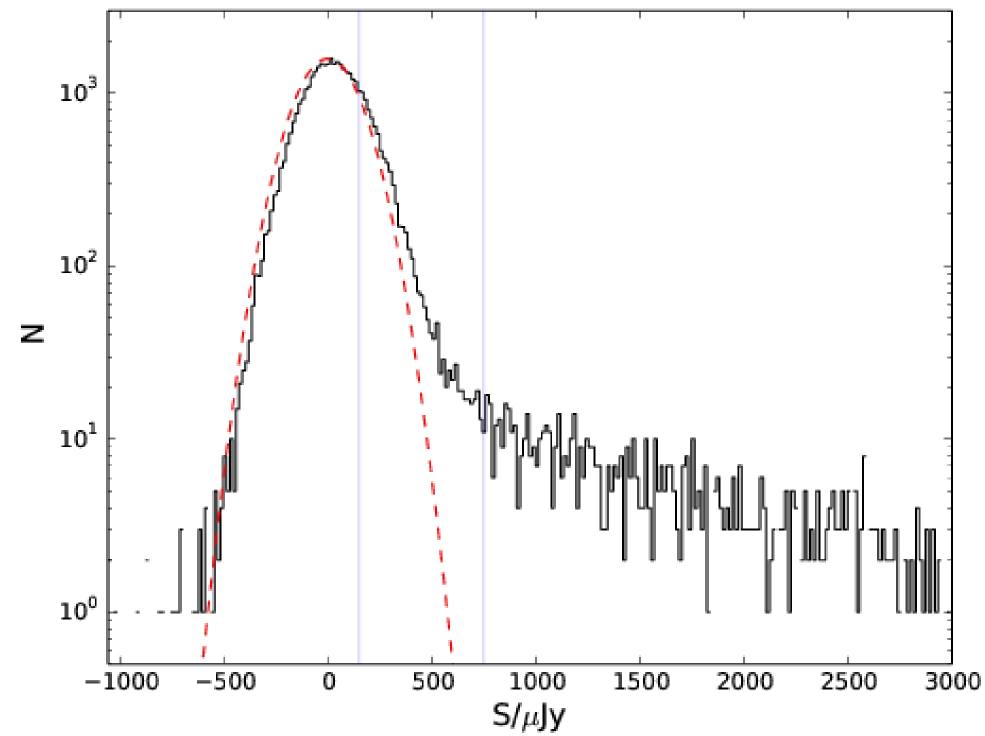
k_i : no: of sources
I_i : mean no: of source

S : Flux
S_m : Noisy Flux
dN/dS : Source counts
σ : Noise rms

Counts to luminosity functions

$$\mathcal{L}_i\left(k_i|\boldsymbol{\theta}\right) = \frac{I_i^{k_i}\mathrm{e}^{-I_i}}{k_i!},$$





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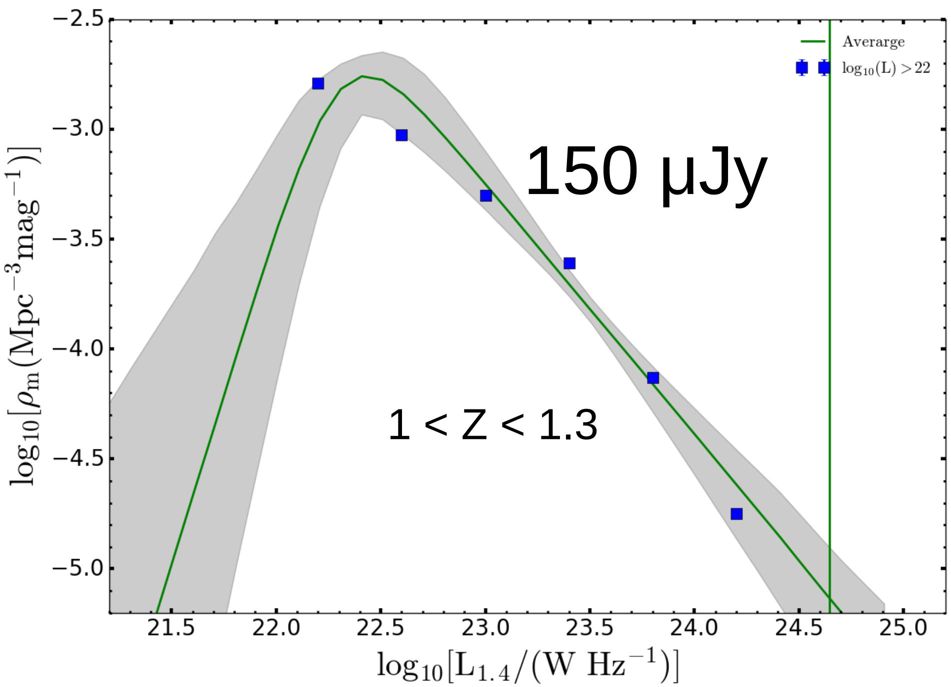
SKA Design Studies: Simulated Skies (SKADS)

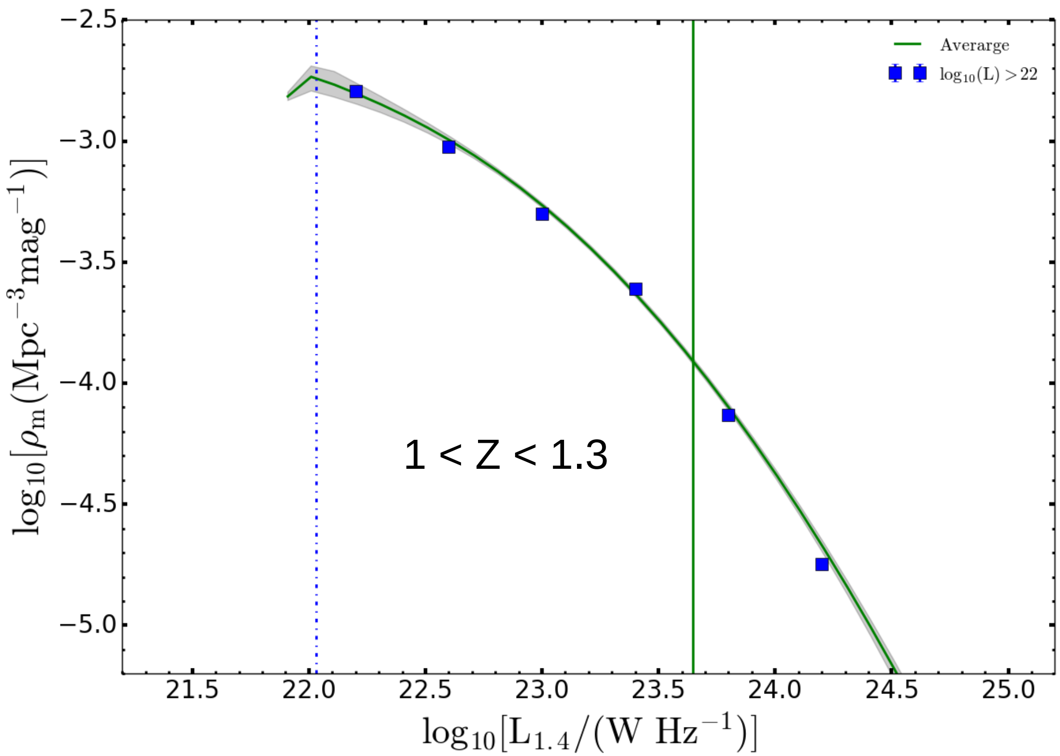
Wilman et al 2010

- 20 deg^2
- Over 320 million sources
- Down to 1nJy



$$\Phi(L) = \frac{\Phi_*/L_*}{(L/L_*)^\alpha + (L/L_*)^\beta}$$

15 μJy



$$\Phi(L) = \Phi_2^* \left(\frac{L}{L_2^*}\right)^{1-\delta} \exp\left[-\frac{1}{2\sigma^2}\log^2\left(1+\frac{L}{L_2^*}\right)\right]$$

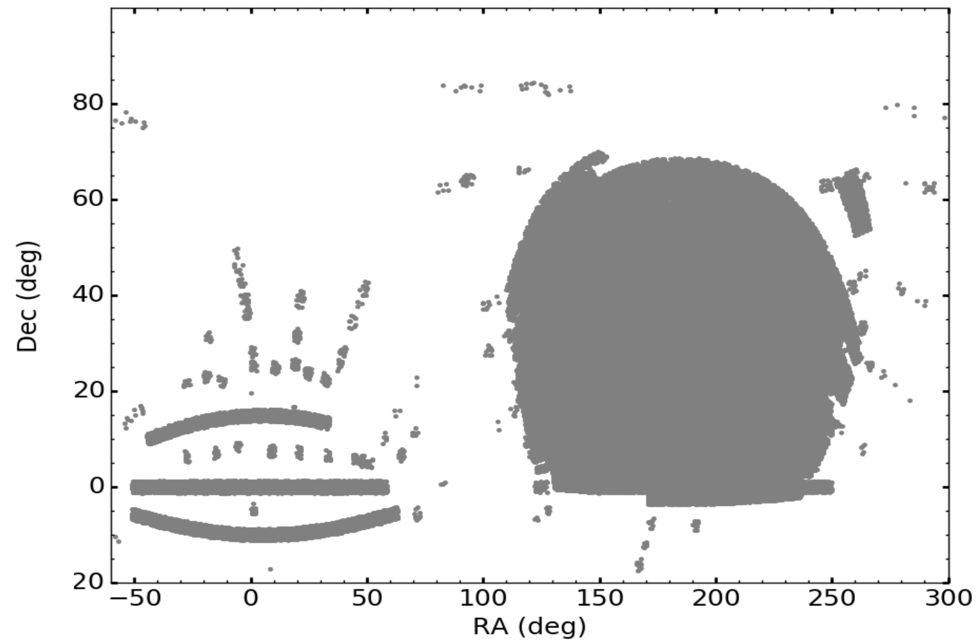
Emission of radio quiet quasars

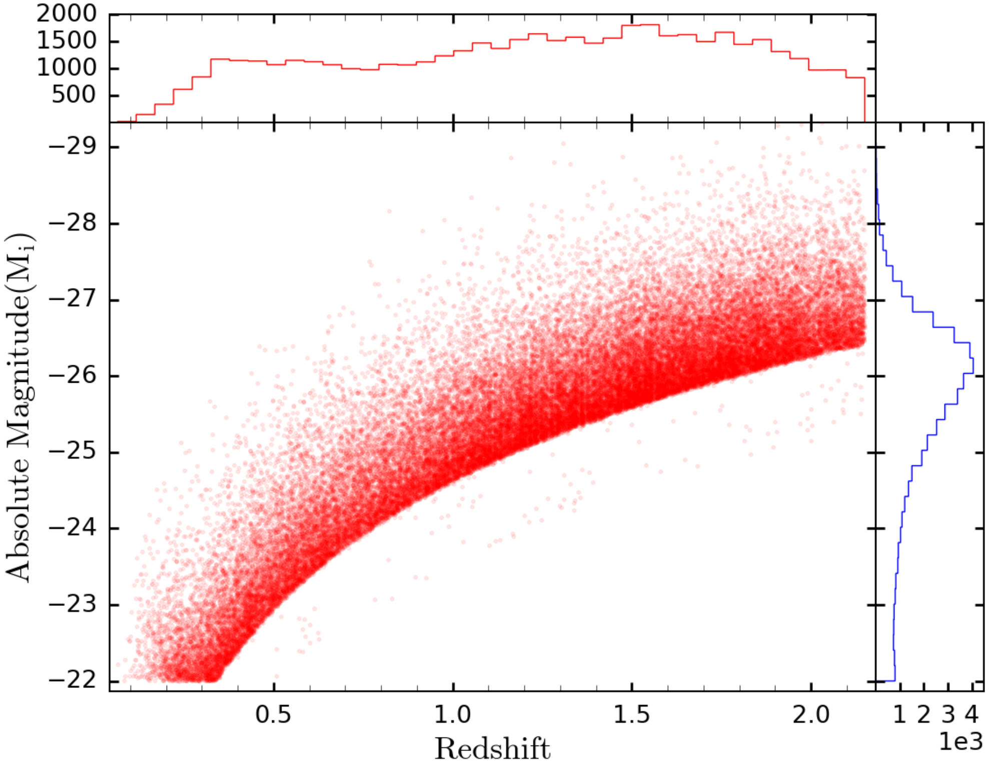
The nature of radio-quiet quasars has been debated for for a long time.

- Are they powered by AGN like radio-loud quasars?
- Or are they powered by star-formation?

SDSS quasars

- Quasars taken from SDSS II DR7. Contains ~ 105 700 sources over ~ 6600 deg^2.
- We use a uniformly selection of source over the footprint (~47 000).



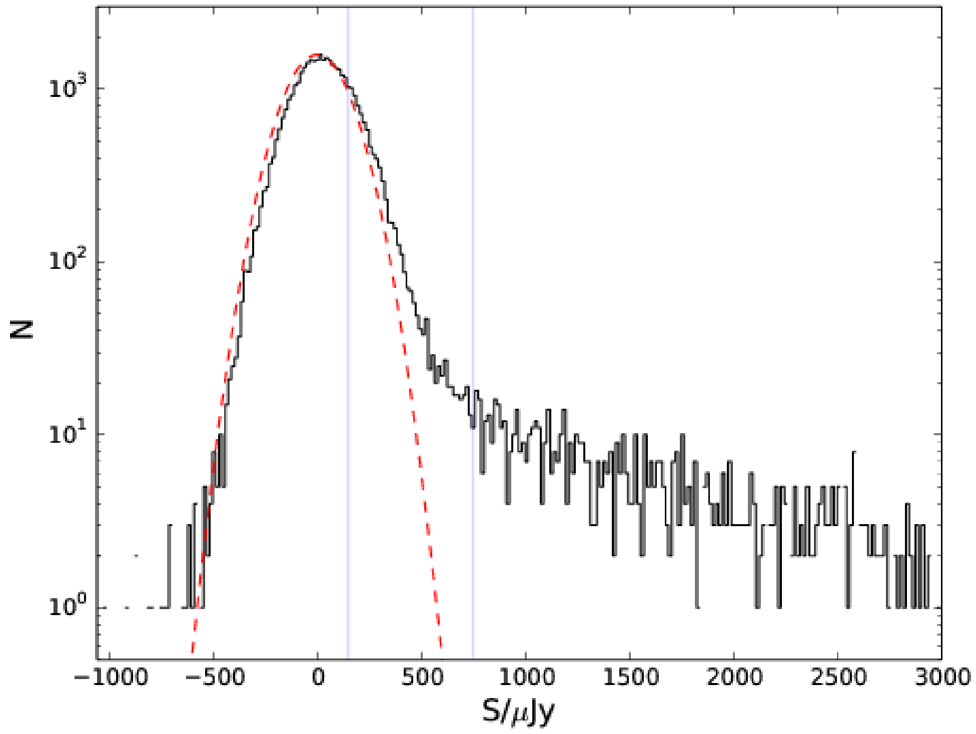


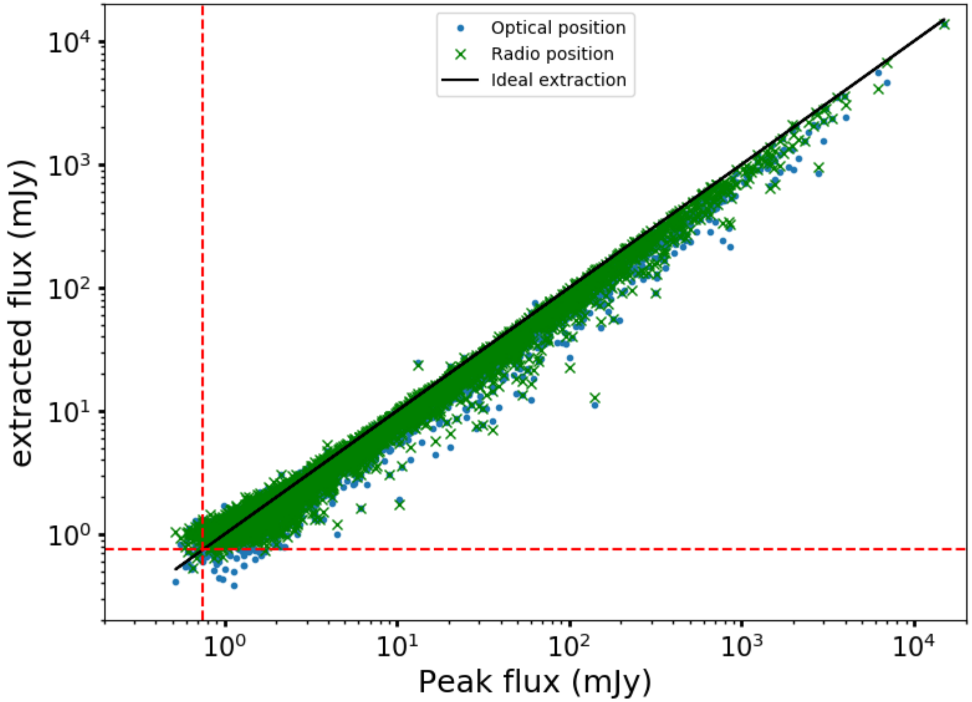
Divide the source into 7 redshift bins to avoid evolutionary effects.

We apply an absolute magnitude cut to each bin to ensure completeness.

Radio data

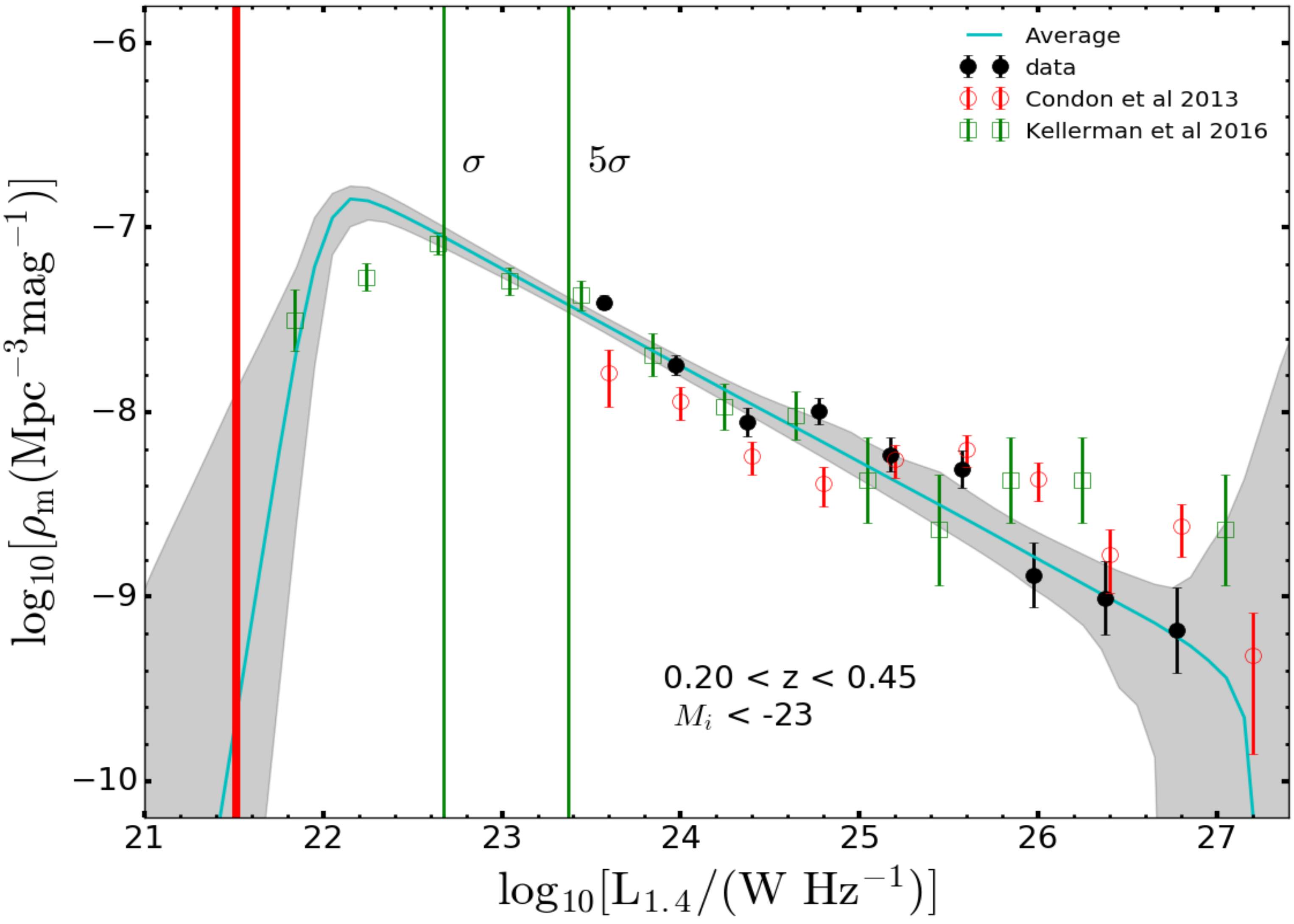
- FIRST survey is taken by the Very Large Array (VLA) at 1.4 GHz. Covers ~10 000 deg^2.





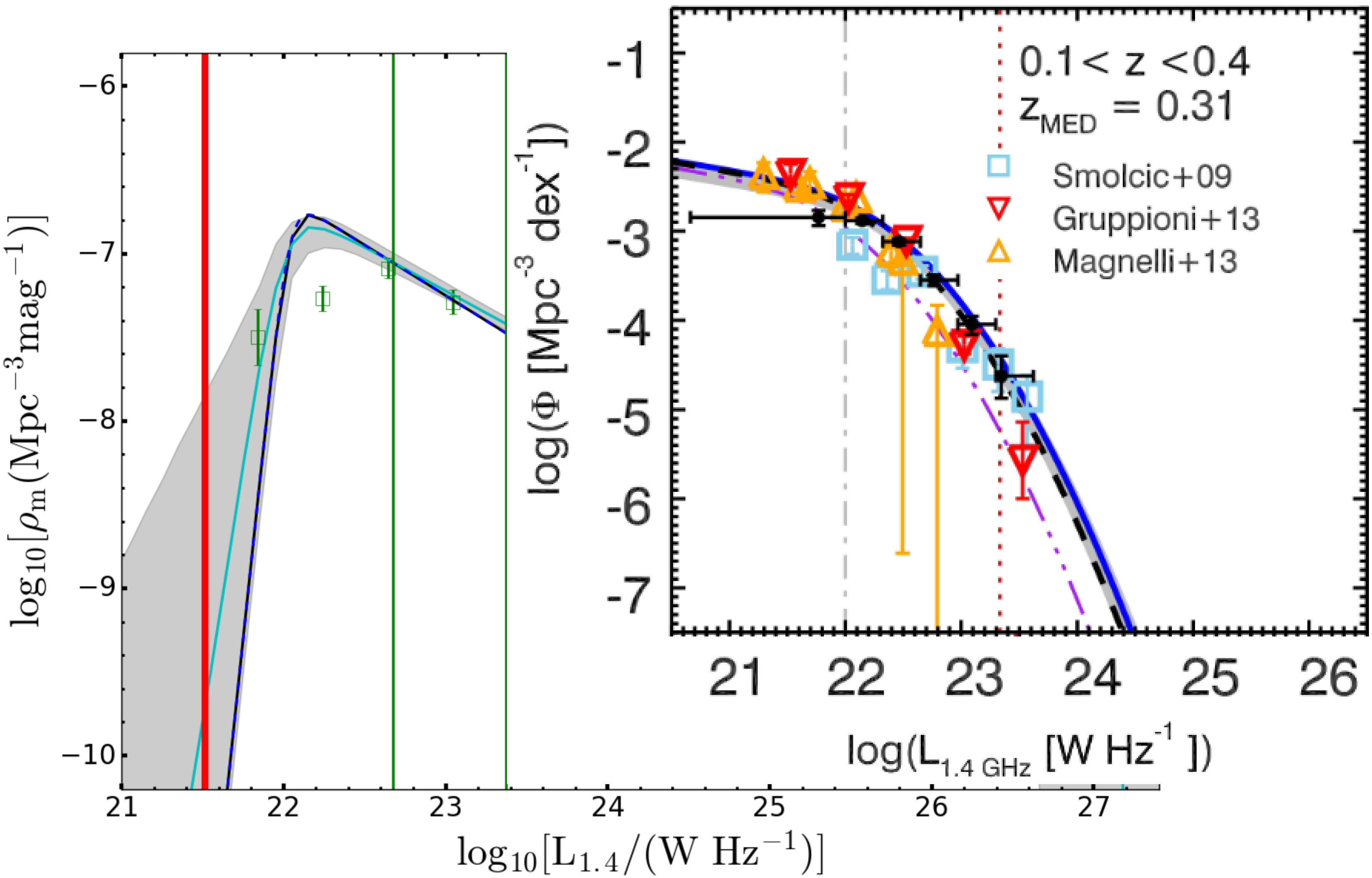
- Radio flux of the quasars extracted at the position of the SDSS quasars.
- ~3800 of the 47 000 have radio counter-parts.

Optically selected quasar radio luminosity function

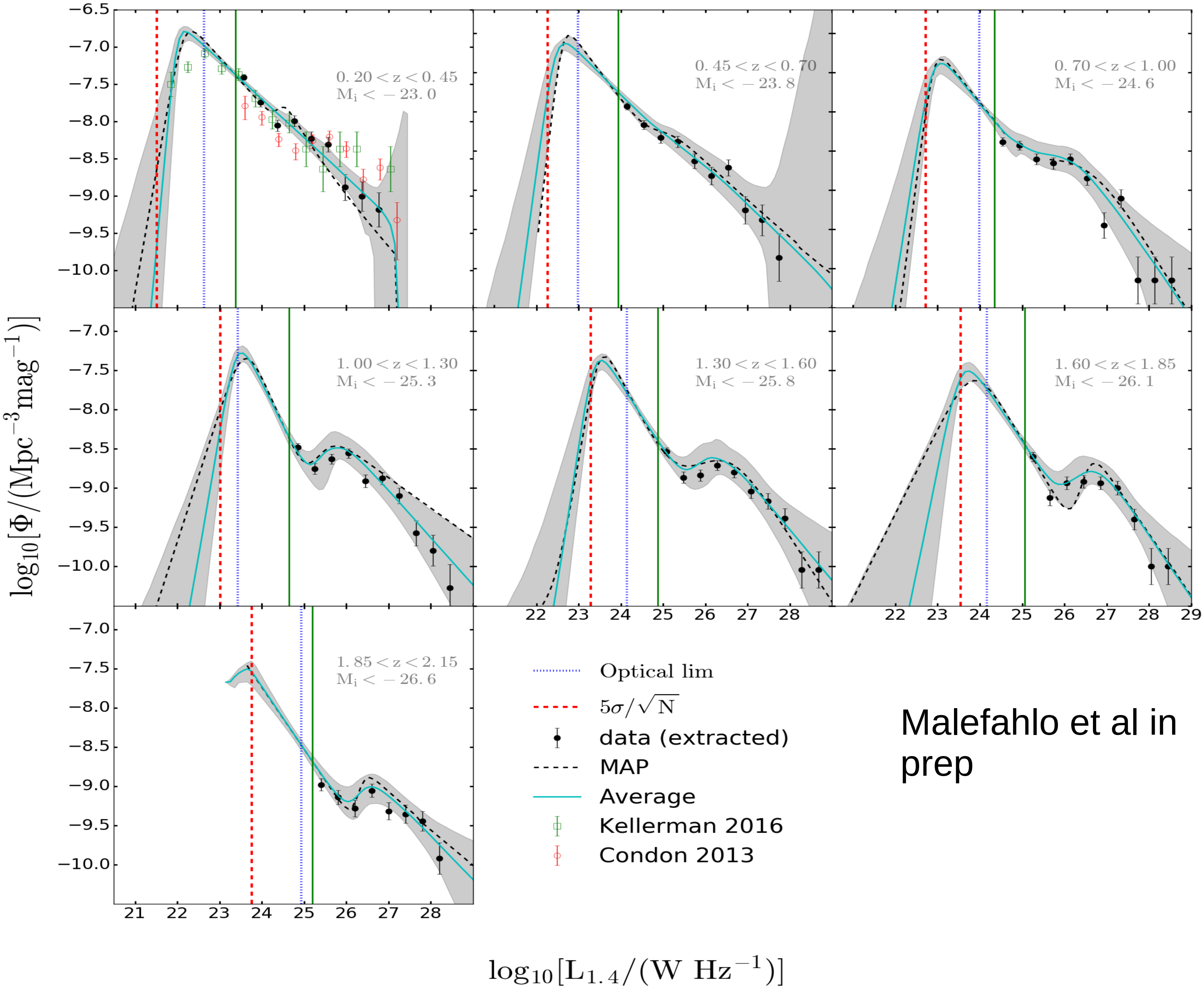


Optically selected quasar radio luminosity function

Novak et al. 2017



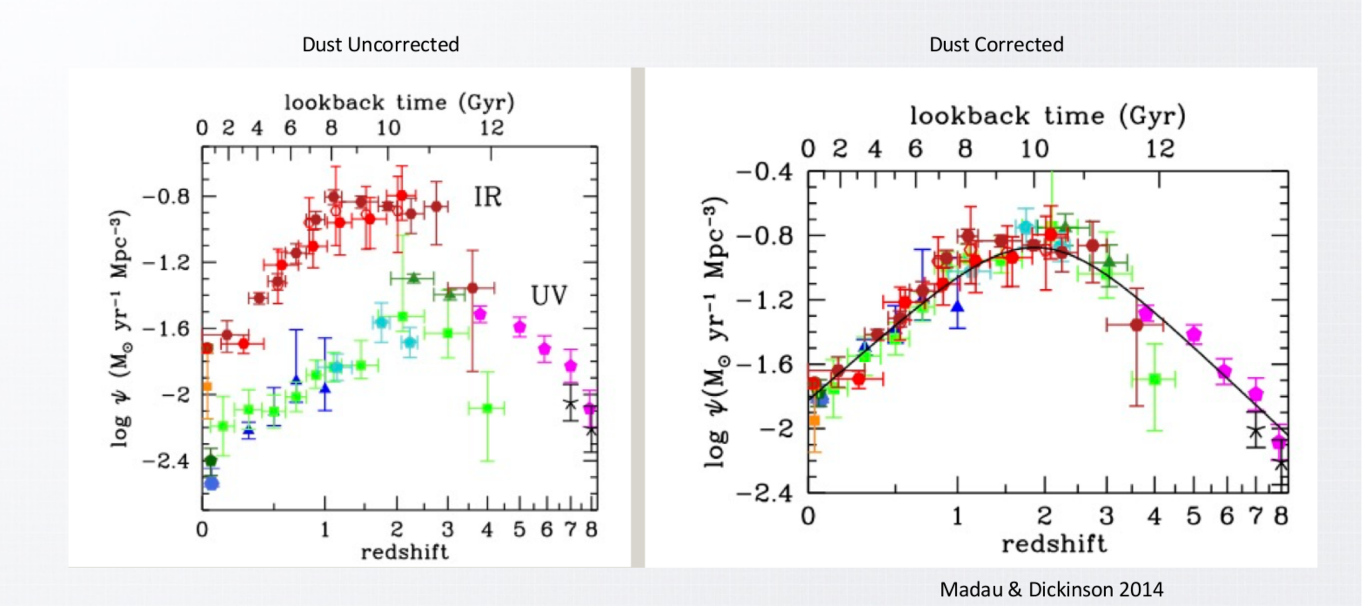
Evolution of QRLF



Malefahlo et al in prep

Cosmic star formation history

- Important in understanding galaxy evolution.
- Star formation traces: UV, Optical, Far-IR and Radio.
- UV and Optical are obscured by dust.

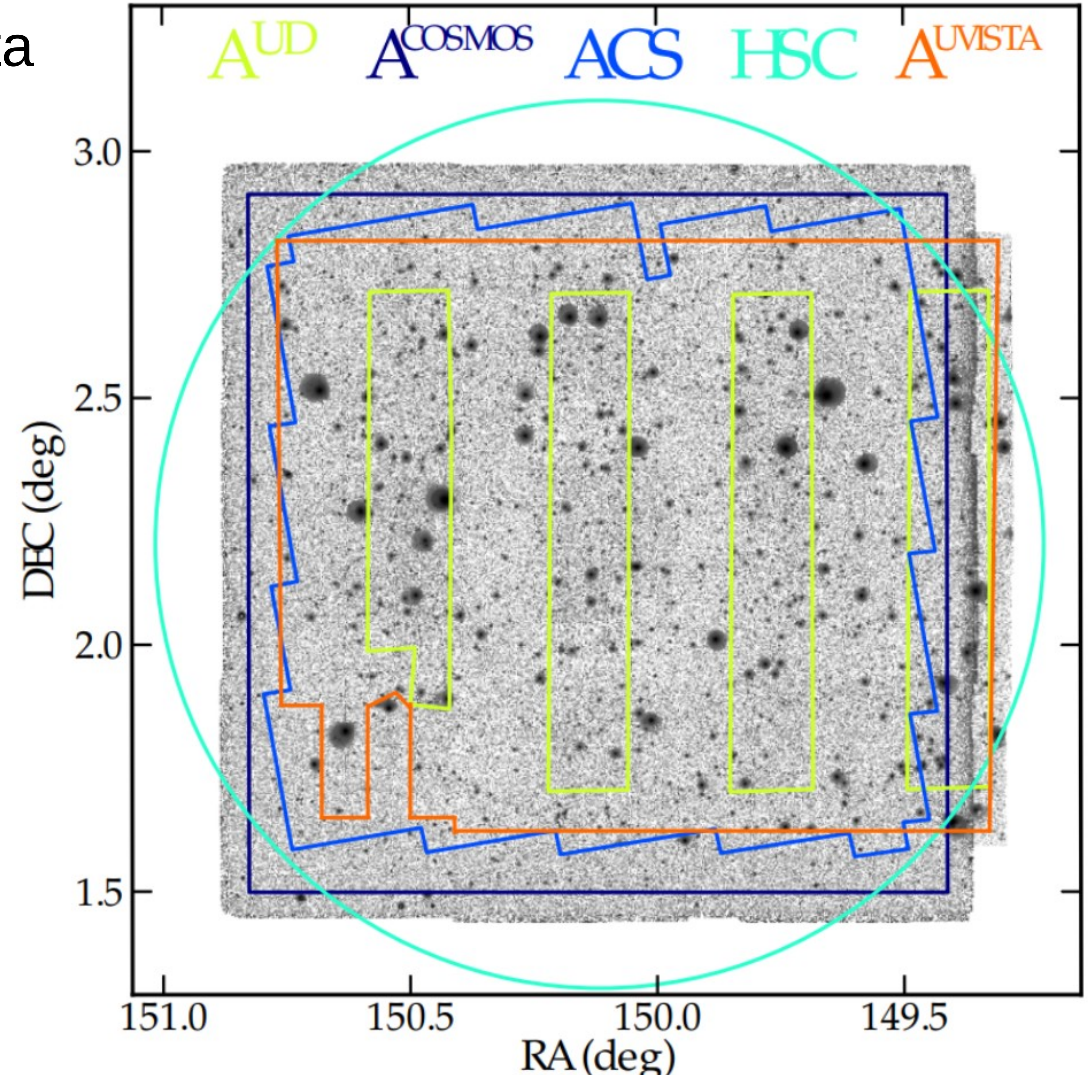


- Far-IR and Radio are not deep enough.
- Push sensitivity of radio measurements through advanced stacking.

Cosmos field

- Wealth of Multi-wavelength data
- Axillary data – UltraVista
  - 1.77 deg
  - 606, 887 sources
  - Ks < 24.7 (3σ)

- Radio data - JVLA
  - 3 GHz
  - 2.6 deg
  - Average rms 2.3 μJy



Laigle et al 2016

Star forming galaxies

Removing bad data

- Ks_flag <0

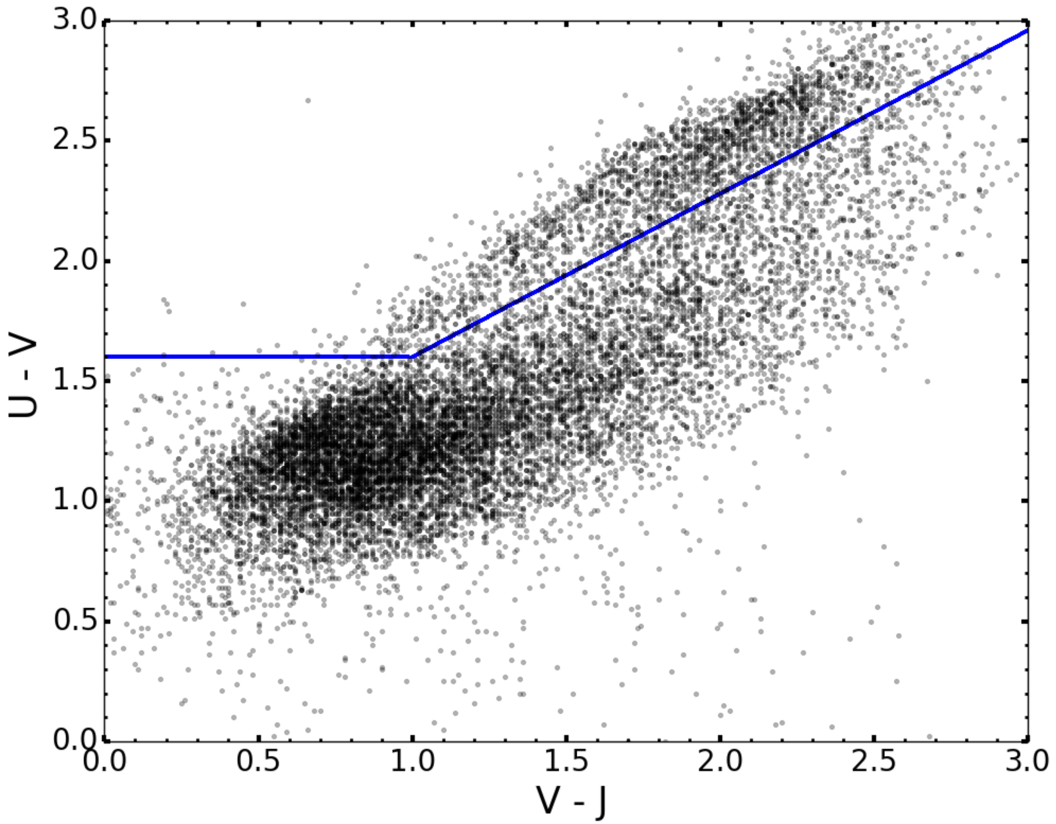
Removing stars

- P(gal) – P(star) > 0

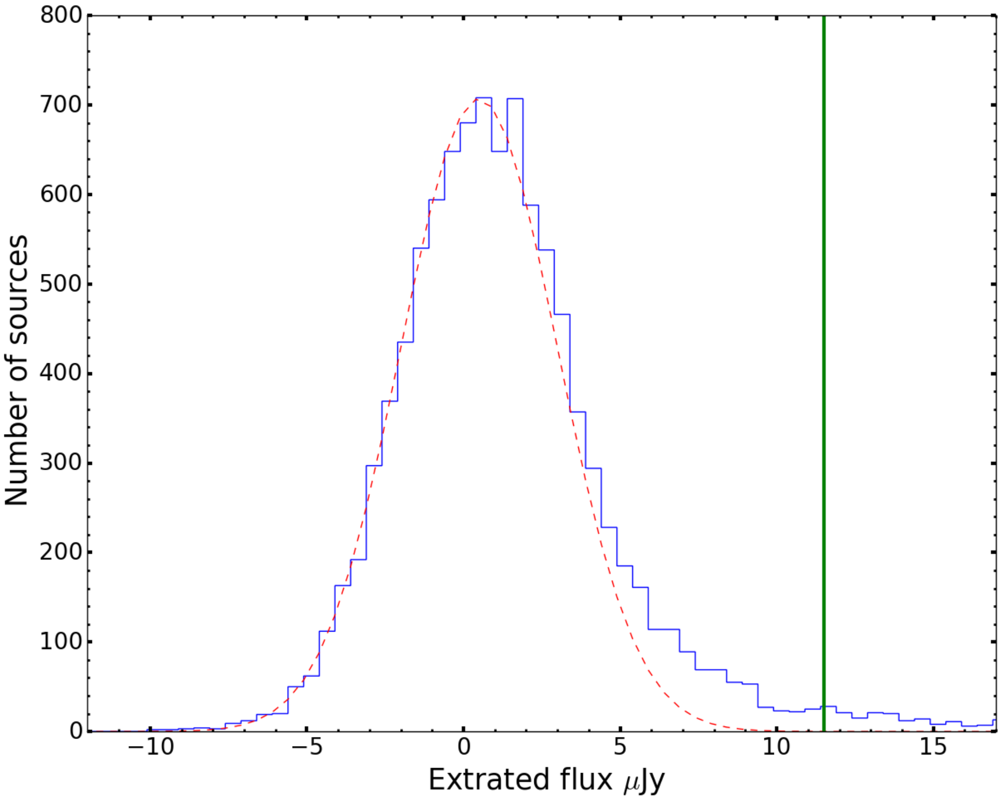
Star-forming galaxies

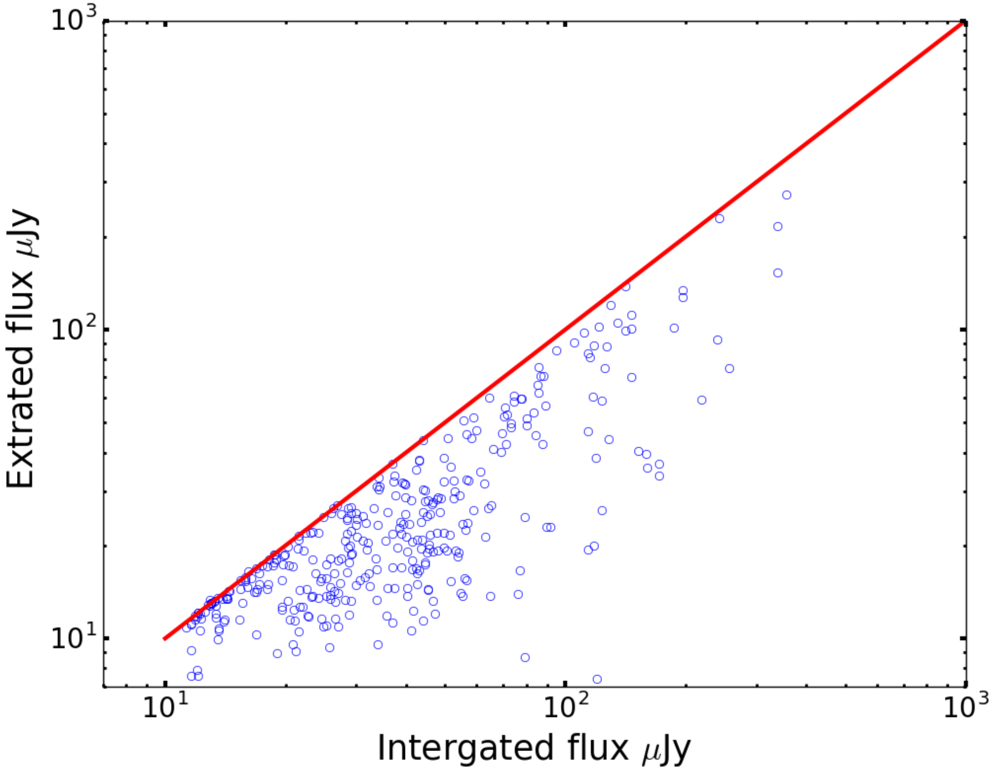
- $(U - V) > 0.88 \times (V - J) + 0.69$

for $0.1 < z < 0.4$

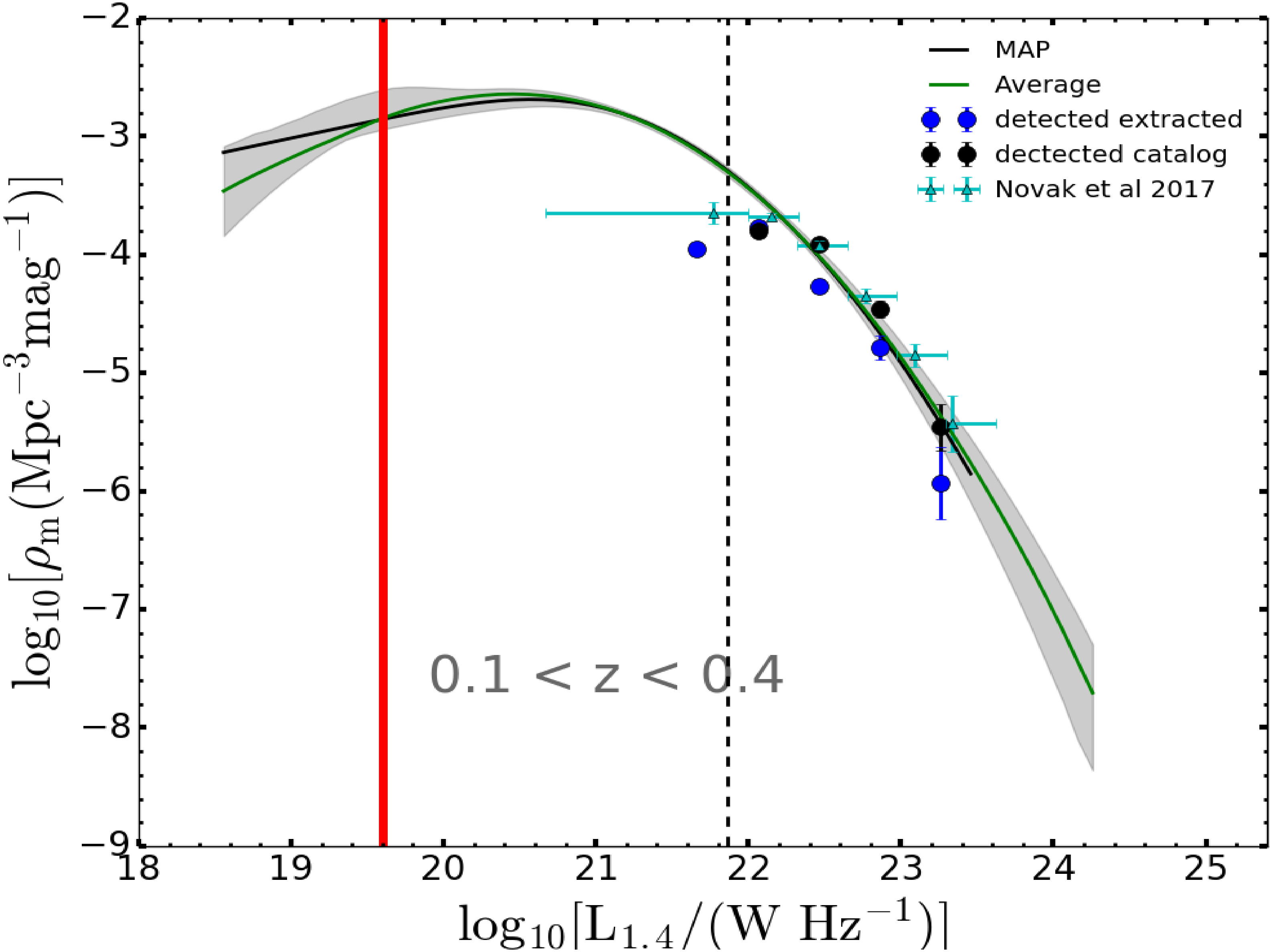


Flux extraction





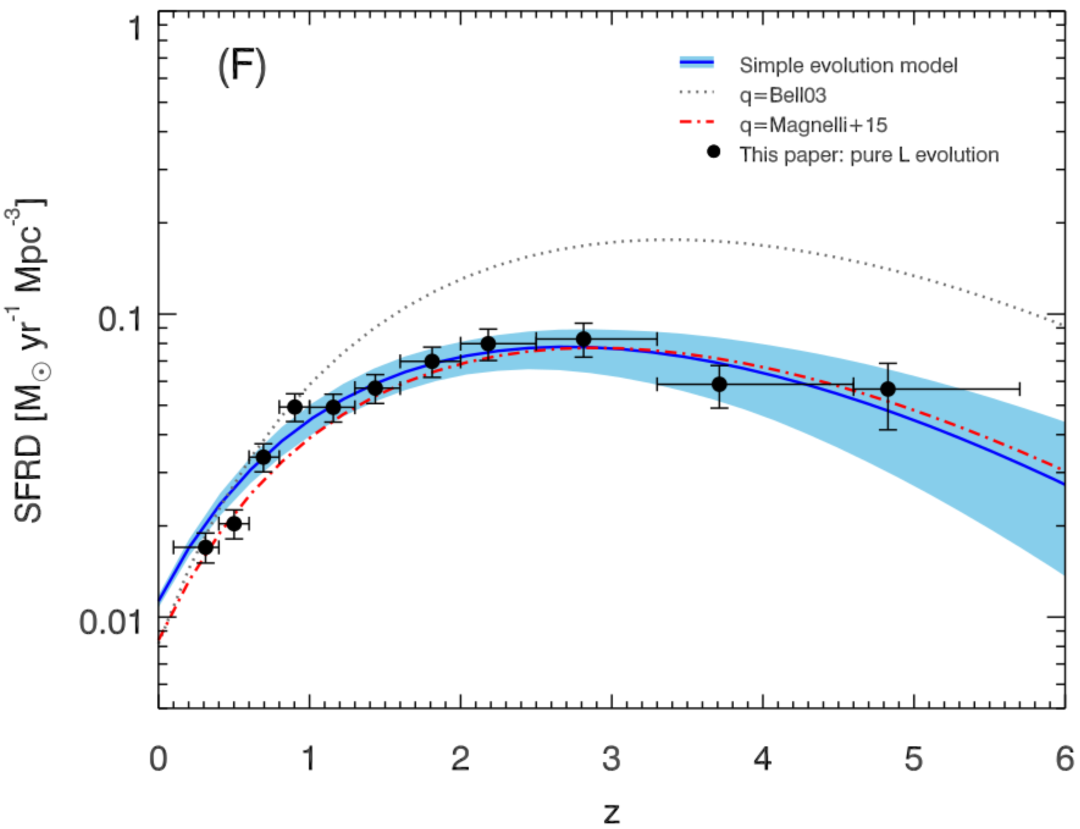
Preliminary results: LF



To do: Cosmic star formation history

- Calculate RLF to z~5
- Star-formation rates using IR – Radio correlation
- Integrate over RLF and SFR to get SFRD

Novak et al. 2017



Summary

- Successfully reconstructed RLF of SKADS sources to more than 2 oders of magnitude.
- The quasar RLF of SDSS-FIRST quasars is in agreement with literature.
- The RLF steeply increases towards the detection threshold which coincides with RLF of starforming galaxies.
- On going project to get star formation history using JVLA.