Title: Radio point sources and SZE surveys

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Abstract:

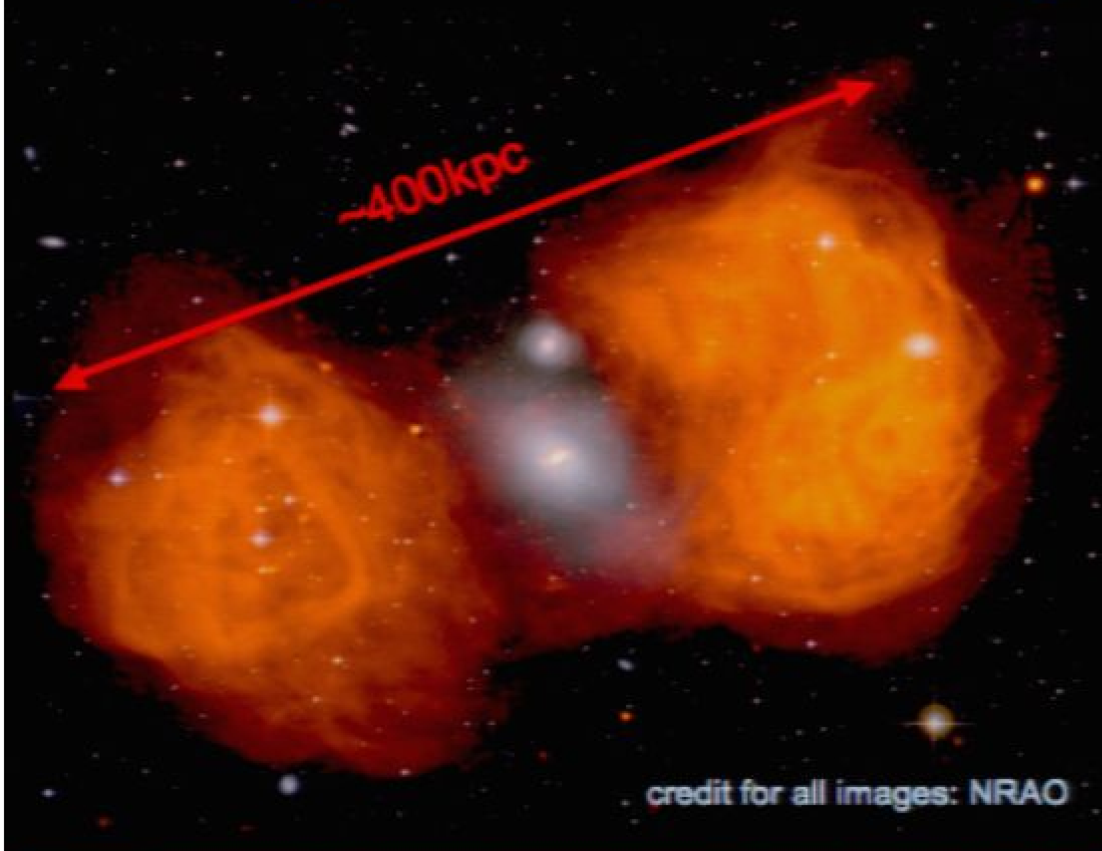
Radio sources and SZE surveys

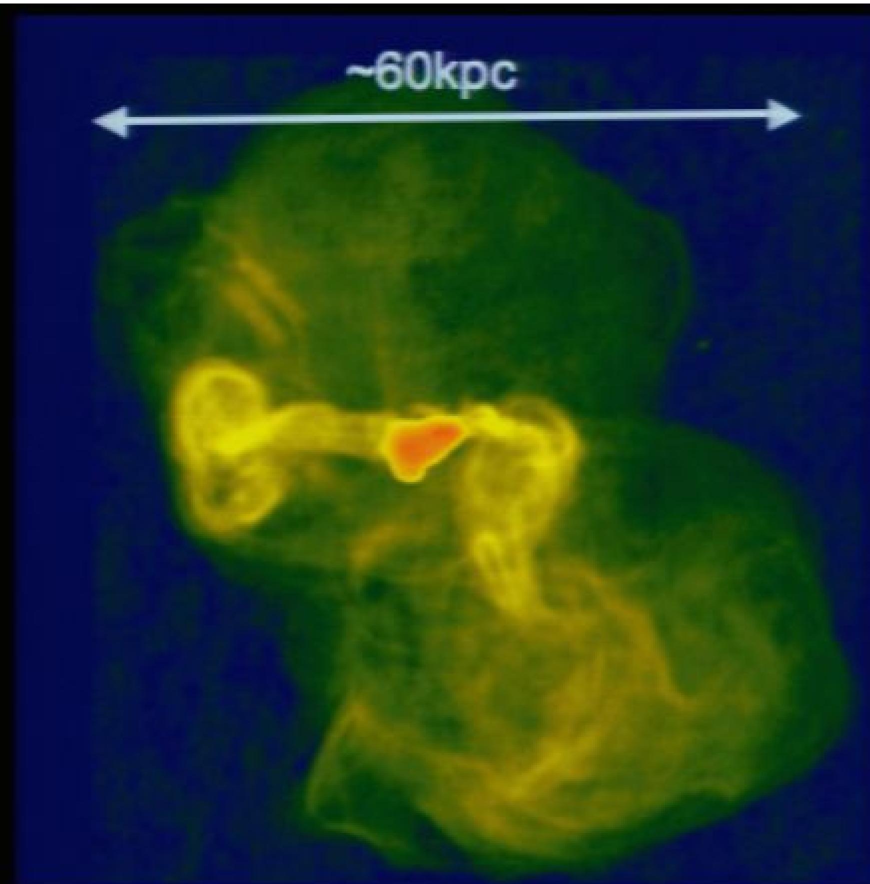
Yen-Ting Lin

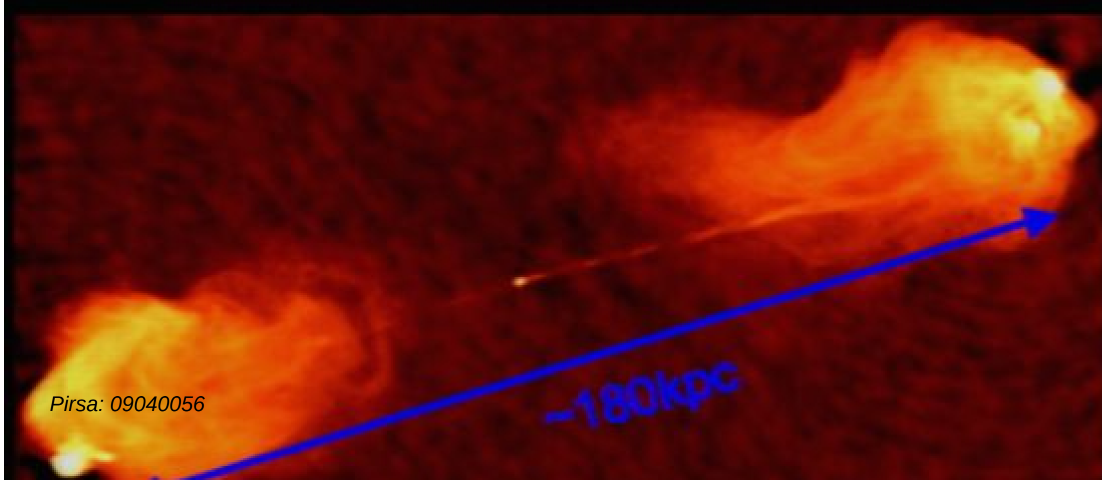
Institute for the Physics and Mathematics of the Universe
University of Tokyo

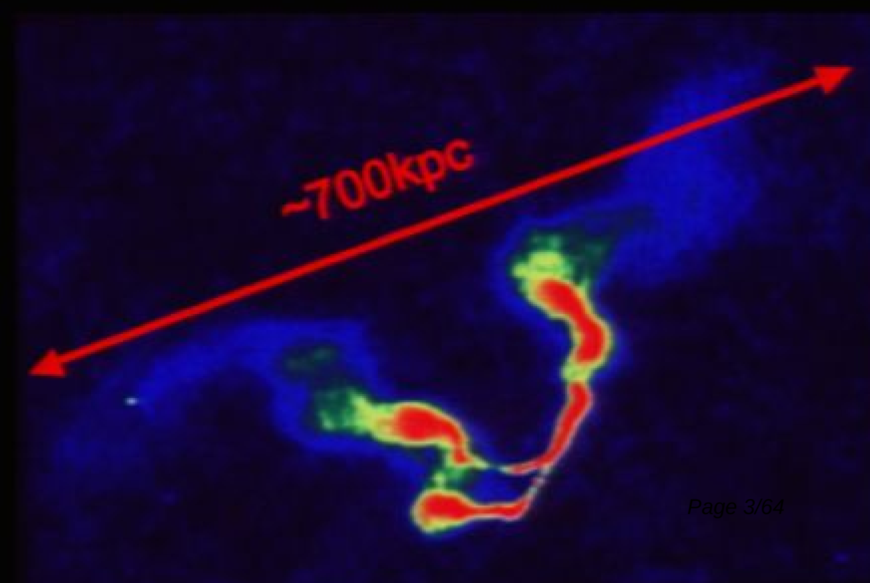
Michael Strauss, Yue Shen, Zheng Zheng, Bruce Partridge,
Kevin Huffenberger, Neelima Sehgal, Hy Trac, Paul Bode,
Carlos Hernandez-Monteagudo, Sudeep Das

radio galaxies can be big

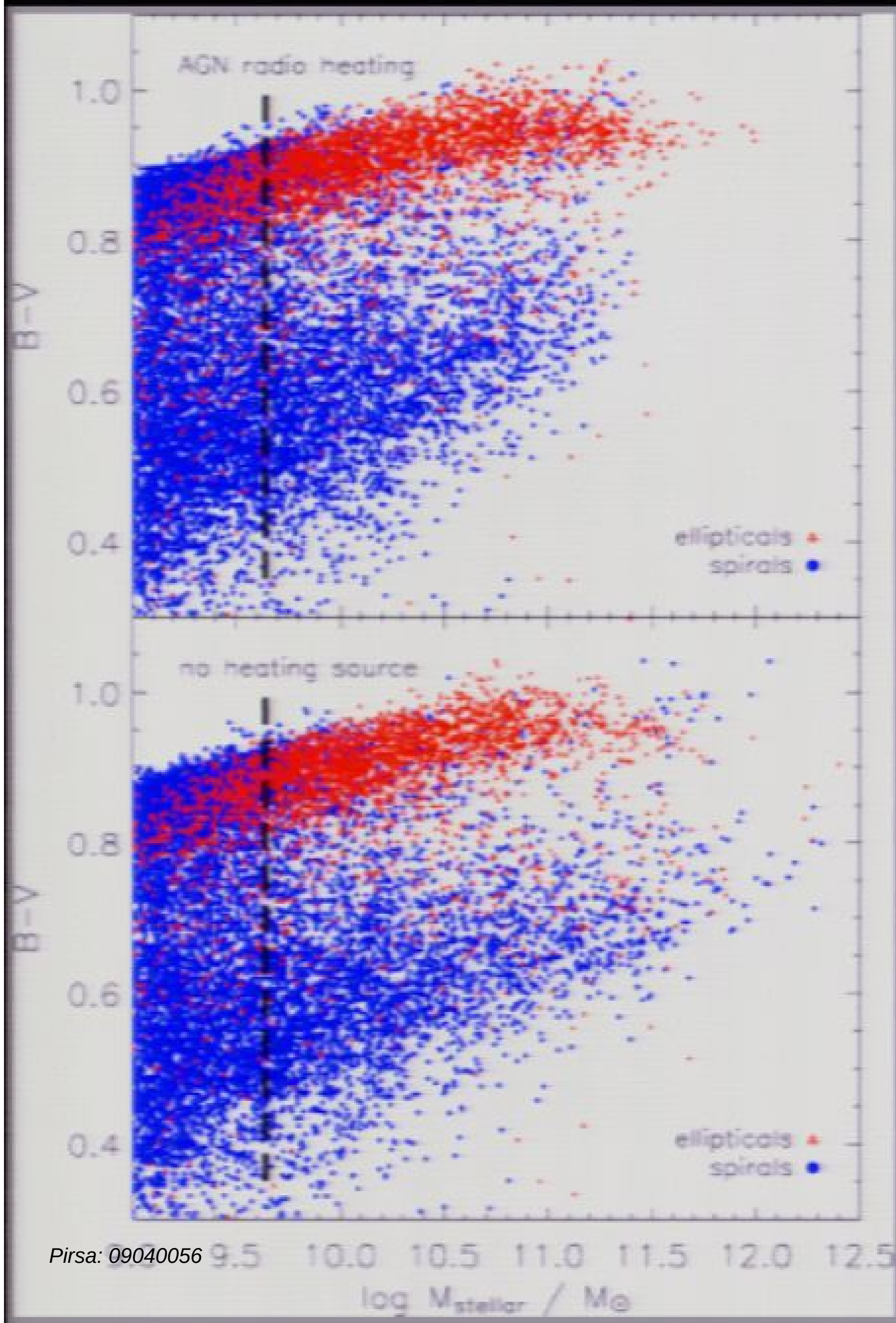


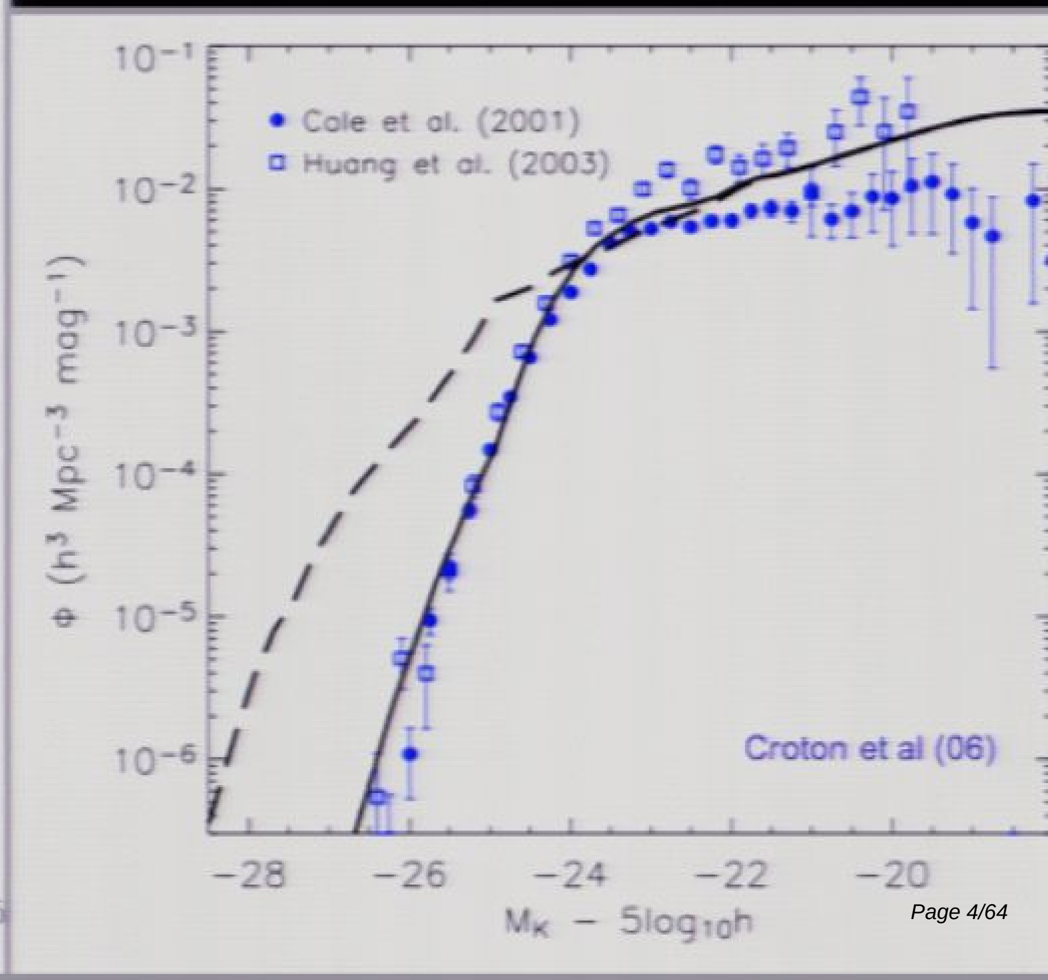






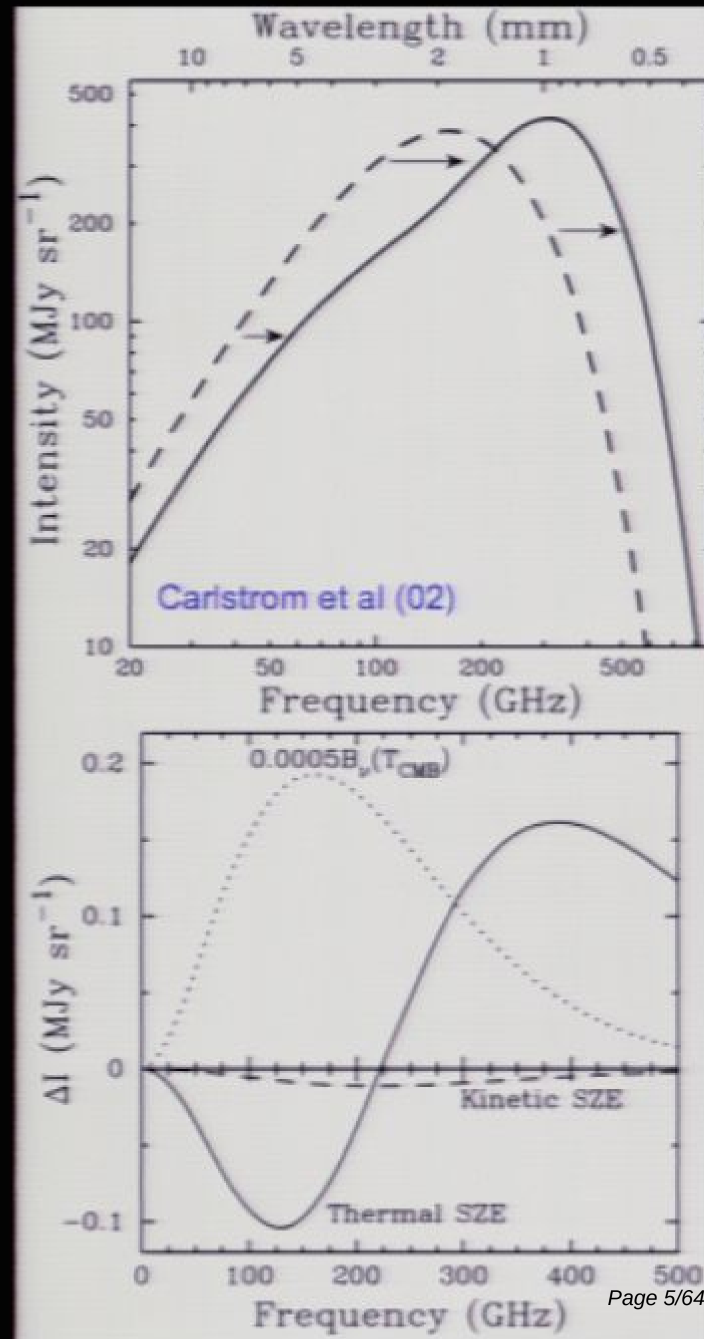
motivation: to make the bright end of the LF and CMD right





motivation: SZE surveys are happening!

- SZE surveys hold great promise to probe cosmology and cluster physics
- potential contaminants
  - radio sources
  - dusty galaxies
- it is critical that we know how they are related to clusters in order to make corrections in the power spectrum and cosmological parameter estimation



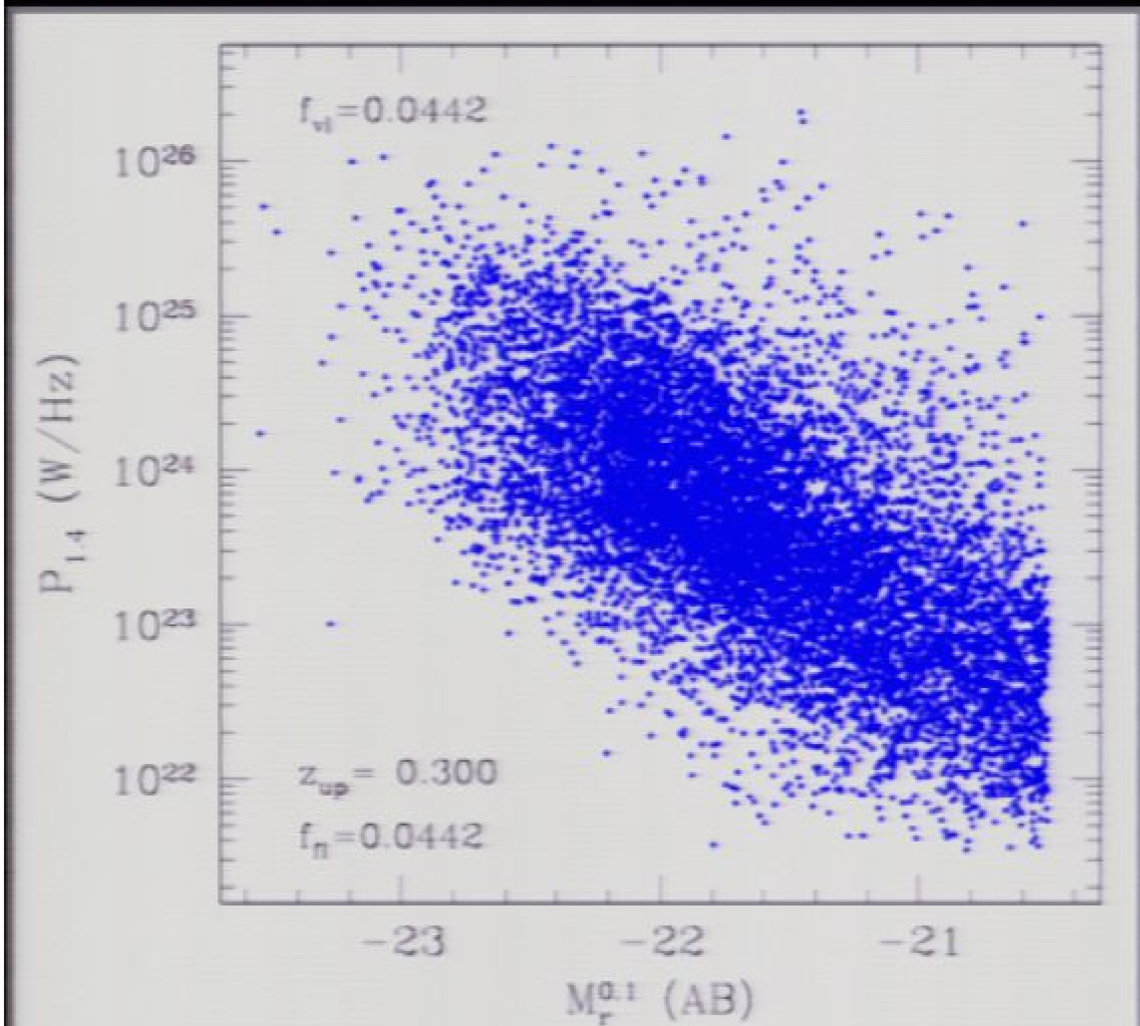
outline

- radio galaxies (RGs) in the local universe
- spectral energy distribution (SED) of cluster radio sources
- a phenomenological model of powerful radio sources

a statistical study of RGs at $z \leq 0.3$

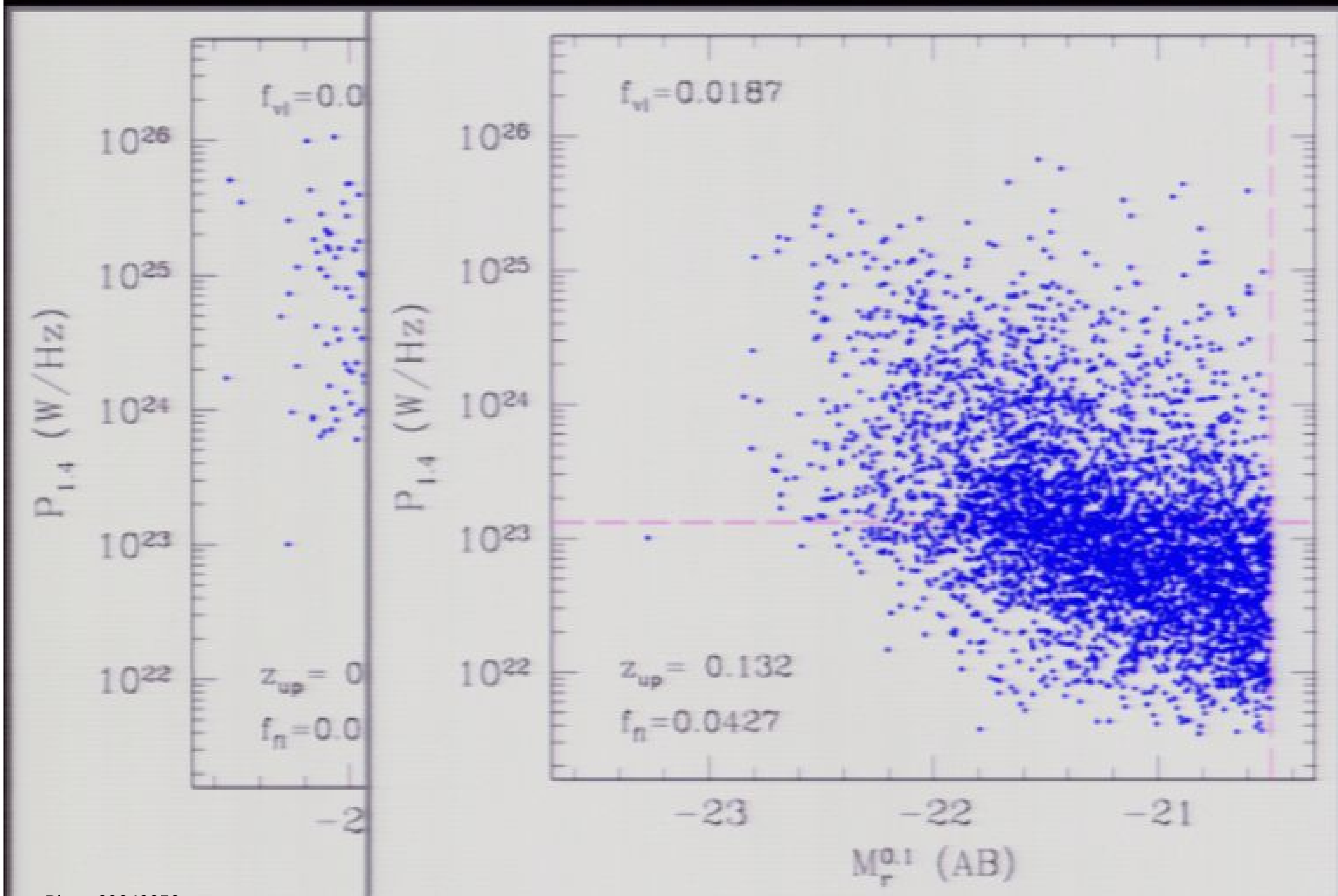
- using SDSS DR6 main galaxy sample as parent sample, containing ~220,000 galaxies down to $M_r \leq -20.5$ (about M_*)
- cross-matched with NVSS and FIRST surveys at 1.4 GHz to generate the largest radio galaxy catalog at $z \leq 0.3$ to date: 10,500 RGs stronger than 3 mJy
- improvements over previous studies
  - construction of several volume-limited subsamples
  - 90% of RGs have measured redshift
  - all RGs visually inspected to secure matches and measurement of fluxes
  - morphology information (FRI, FRII, NAT, WAT, etc) of radio sources
  - high S/N measurement of correlation functions
  - halo occupation distribution (HOD) modeling

bivariate luminosity function



whole sample

bivariate luminosity function



whole sample M≤−20.5 volume-limited

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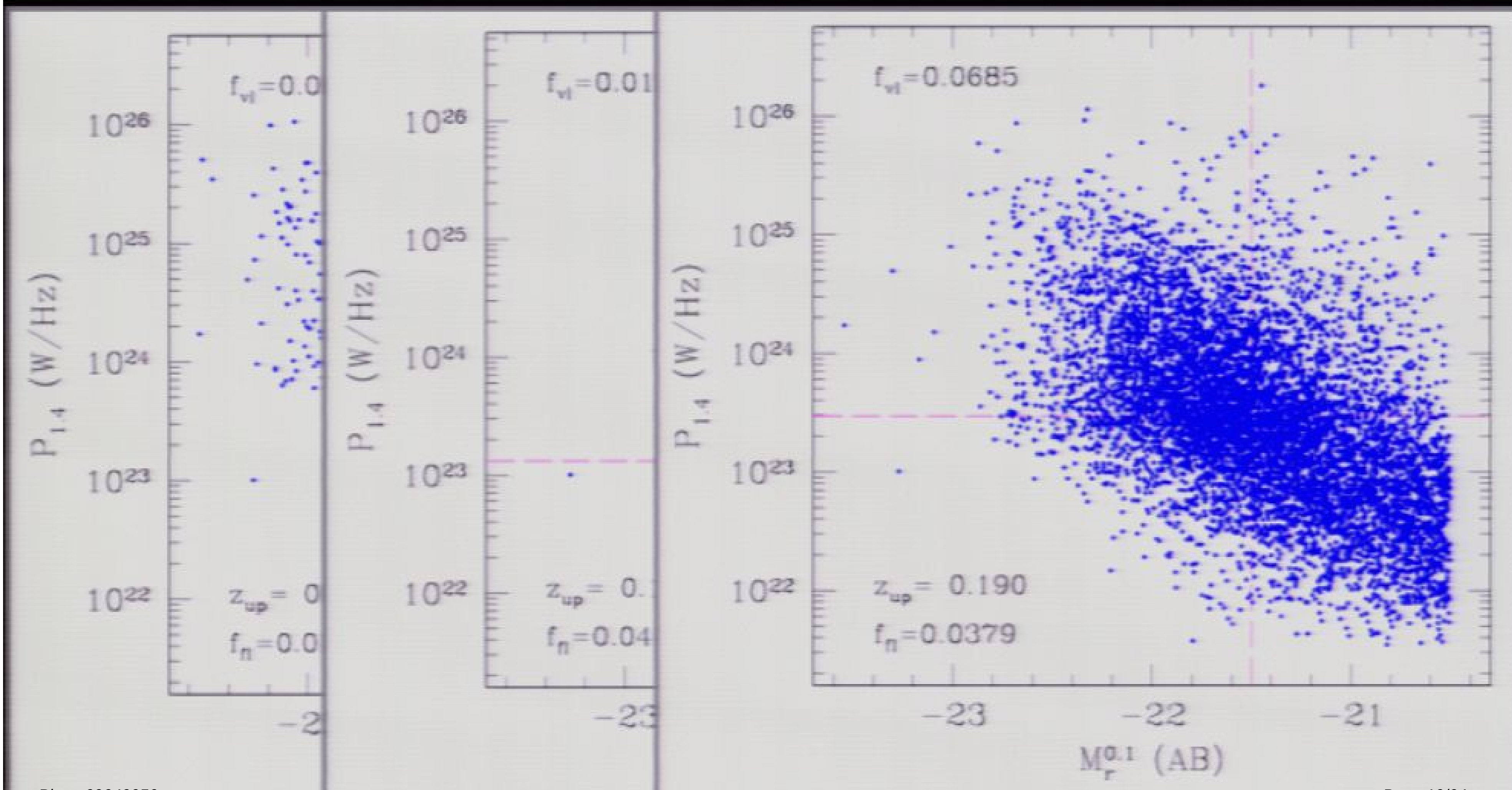
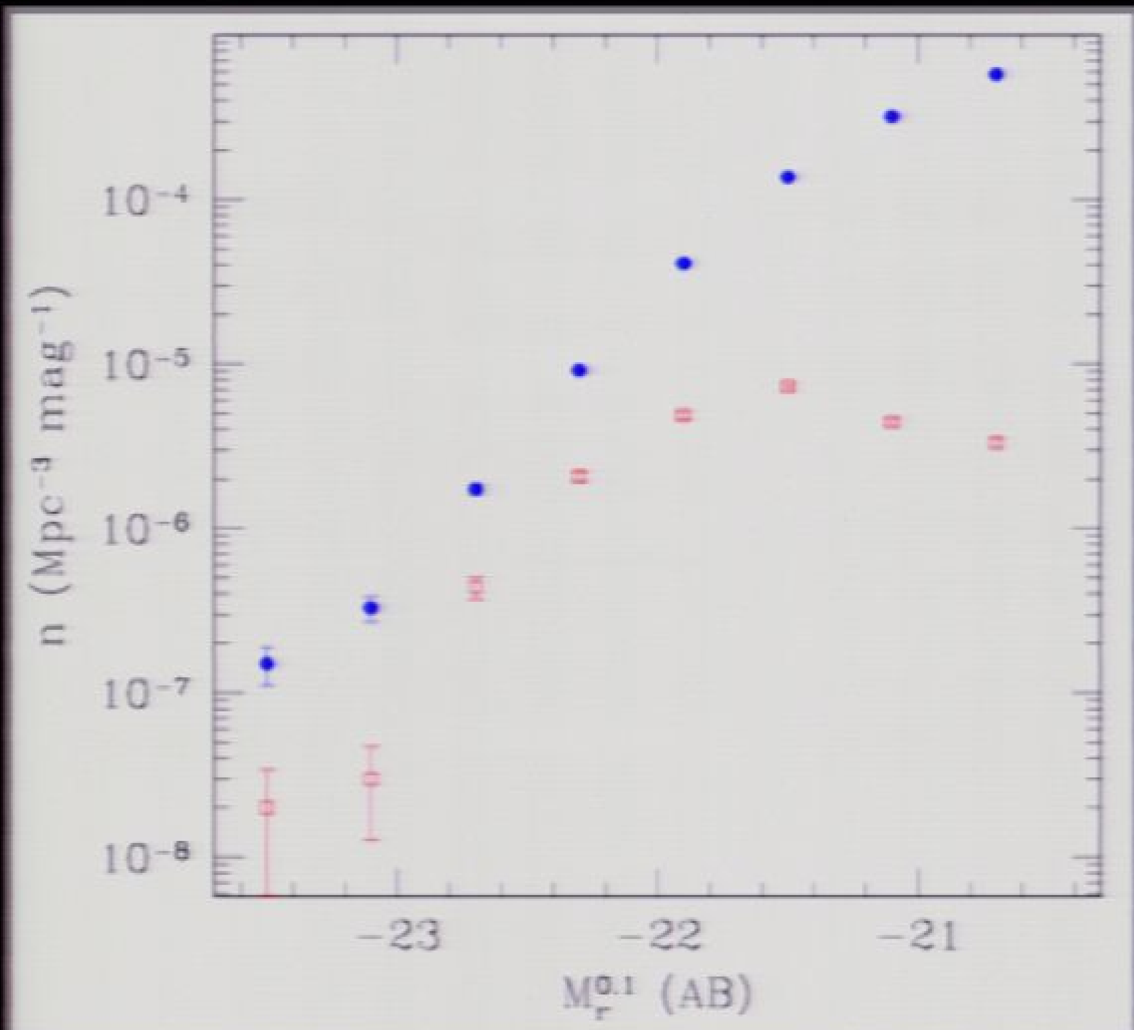


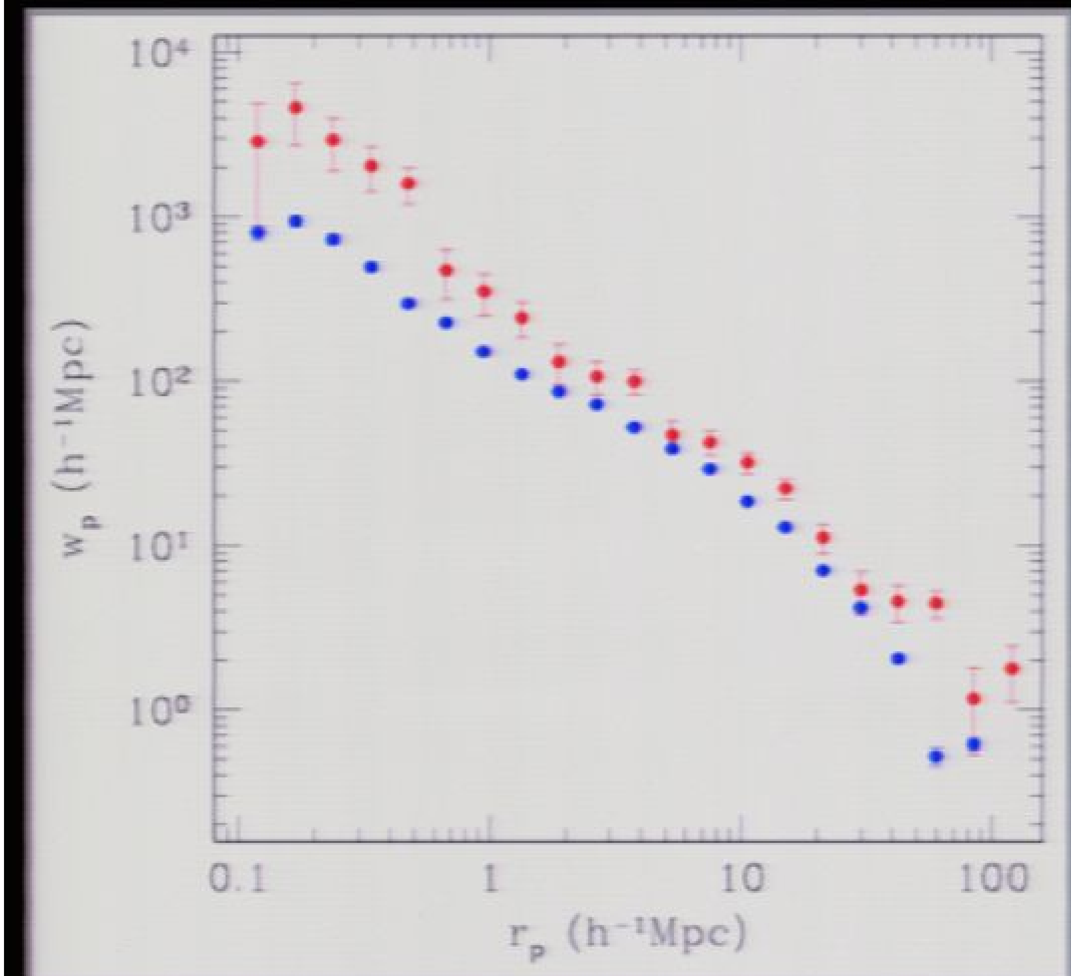
whole sample M≤−20.5 volume-limited M≤−21.5 volume-limited

optical luminosity function



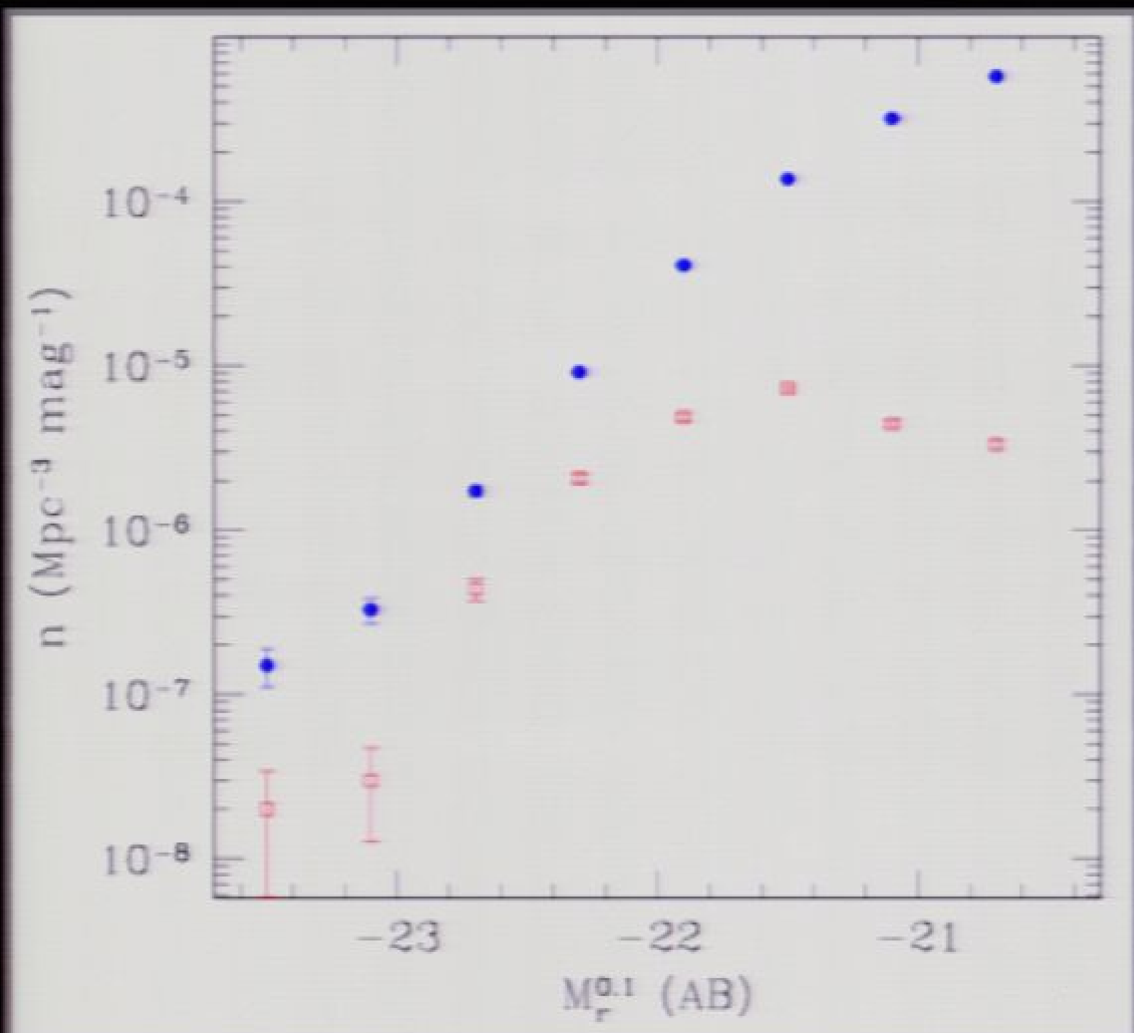
- 0.02≤z≤0.132
- 108,873 galaxies
- 2,253 RGs
- 2.1% of galaxies more luminous than M. have radio power logP≥23.12
- fiber collision correction applied

projected correlation function



- both galaxies and RGs are volume-limited and subject to same optical luminosity cut ($M_r \leq -21.5$)
- RGs more strongly clustered than galaxies

optical luminosity function



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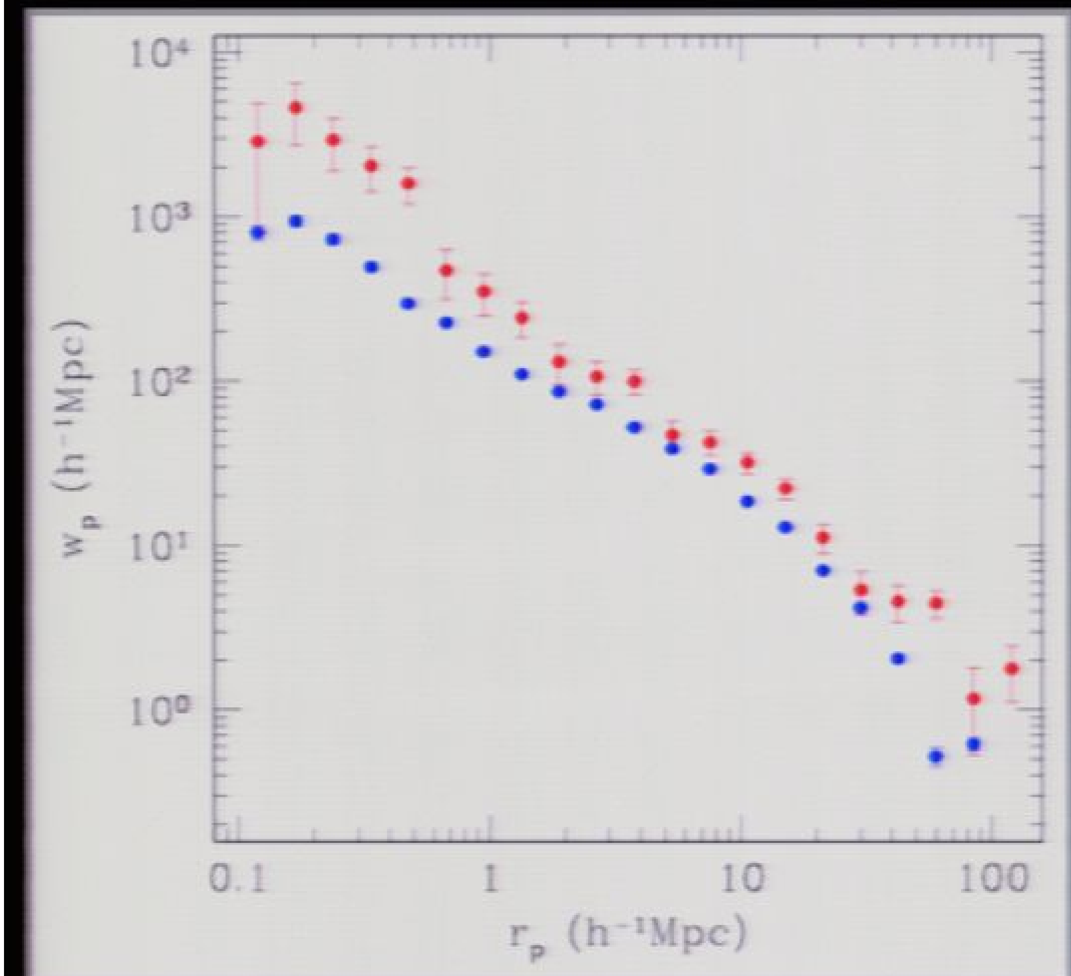

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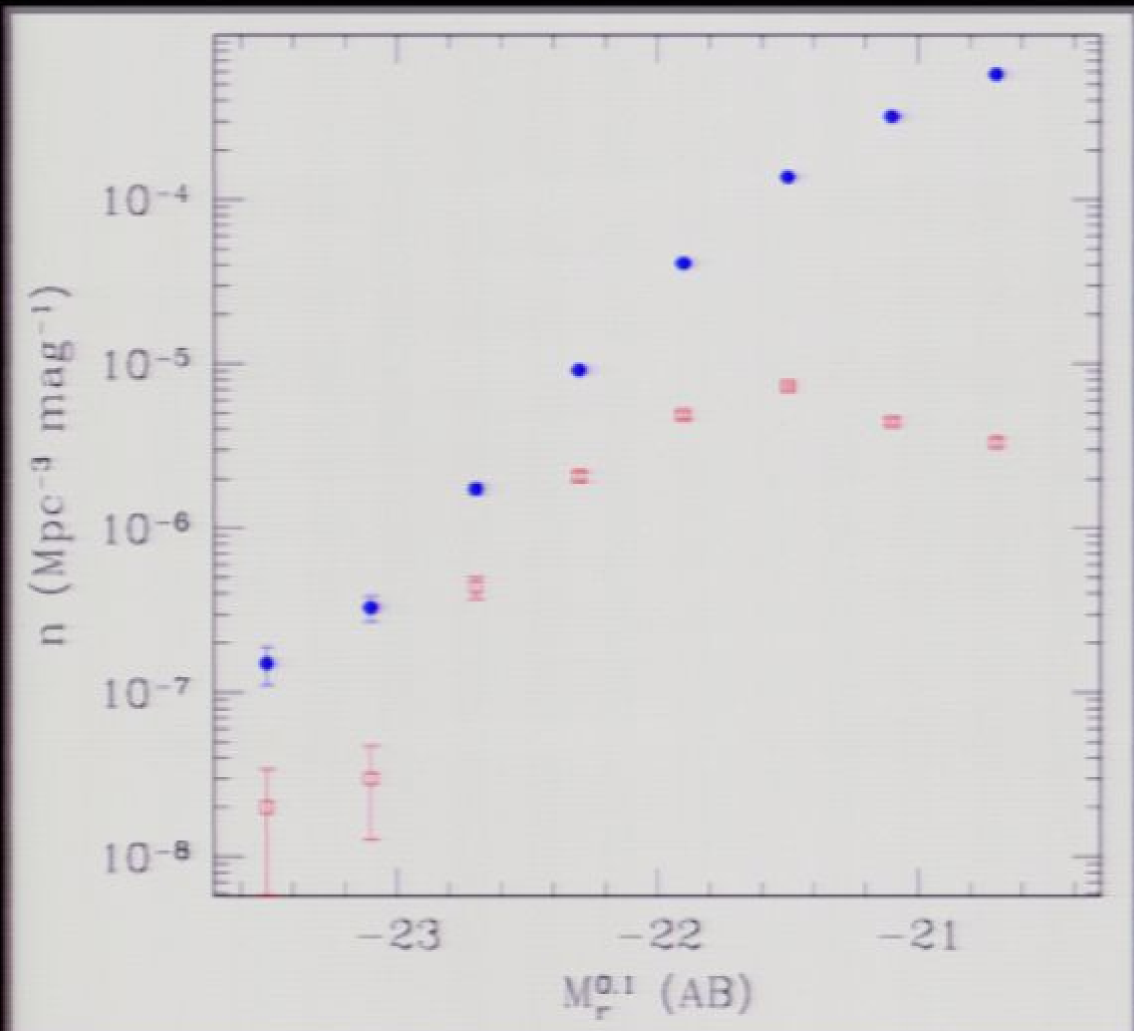

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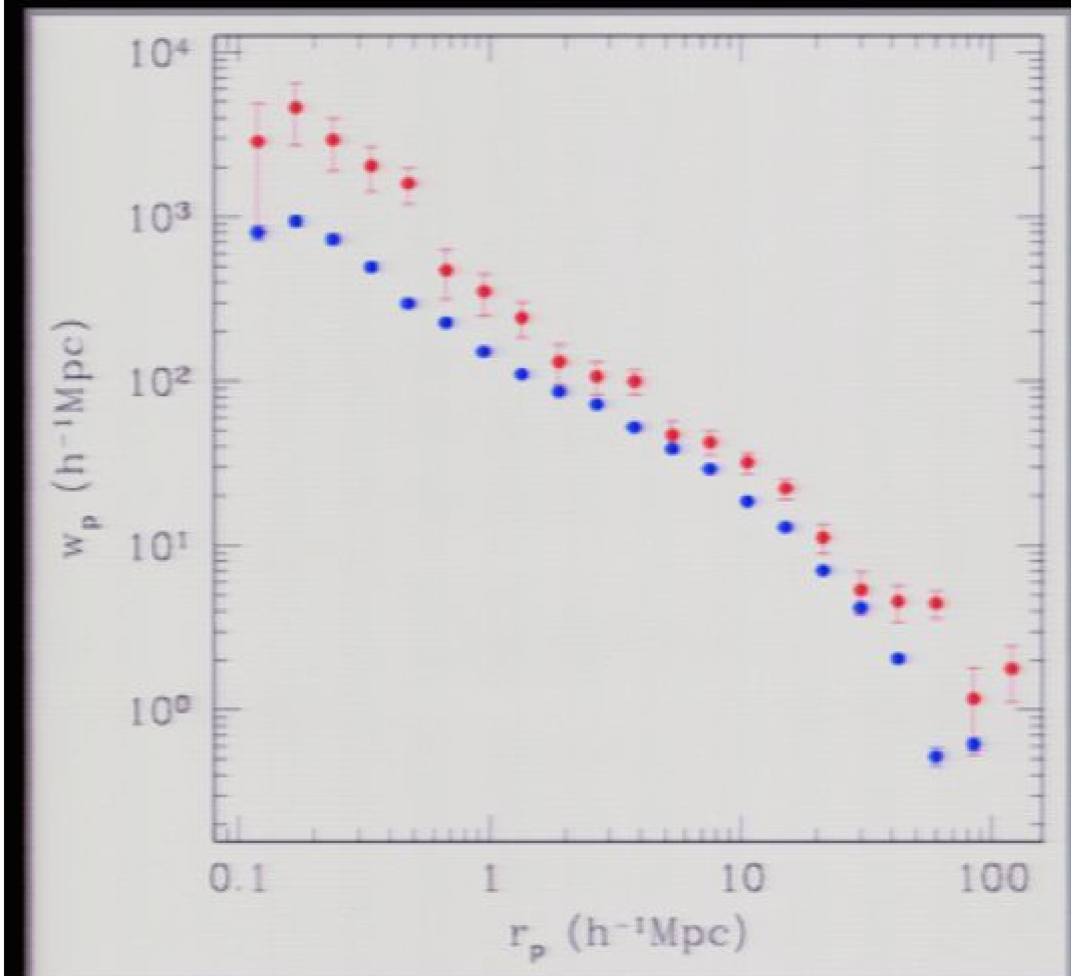

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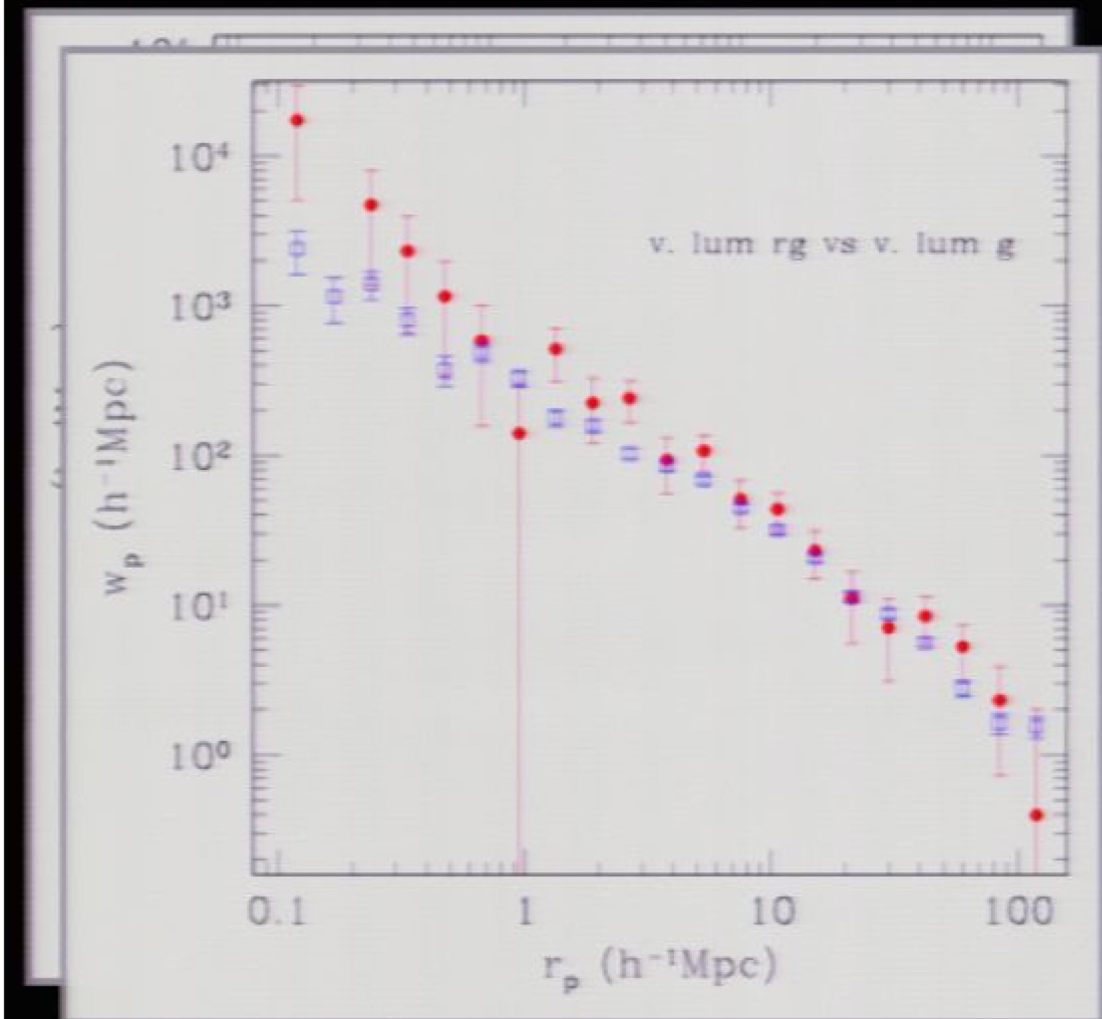

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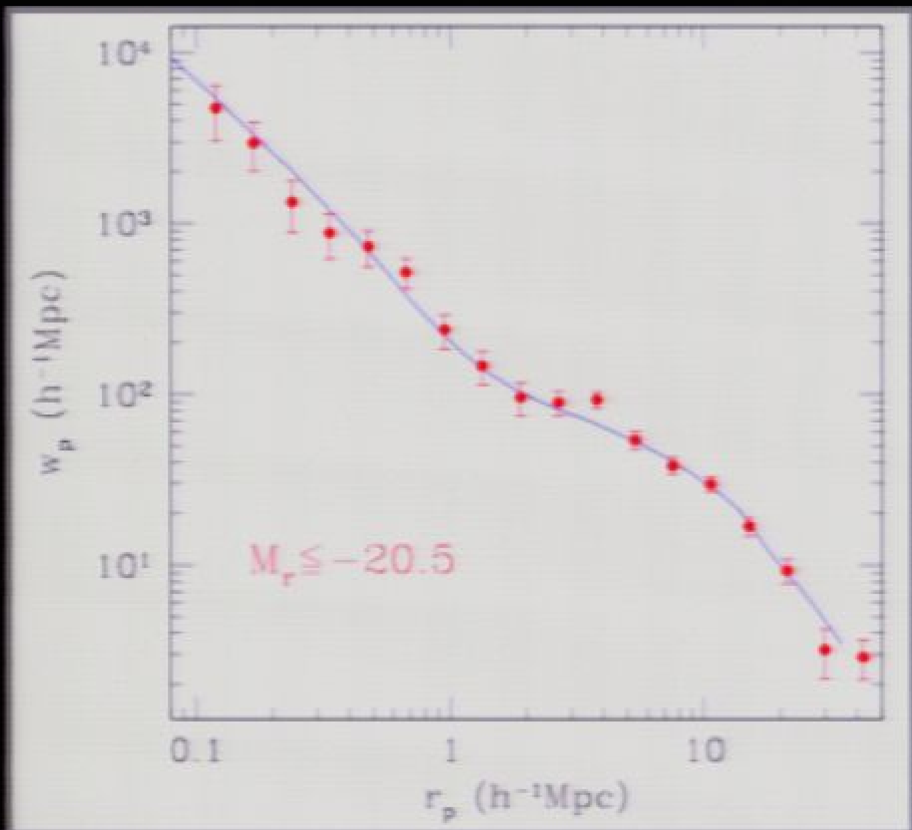
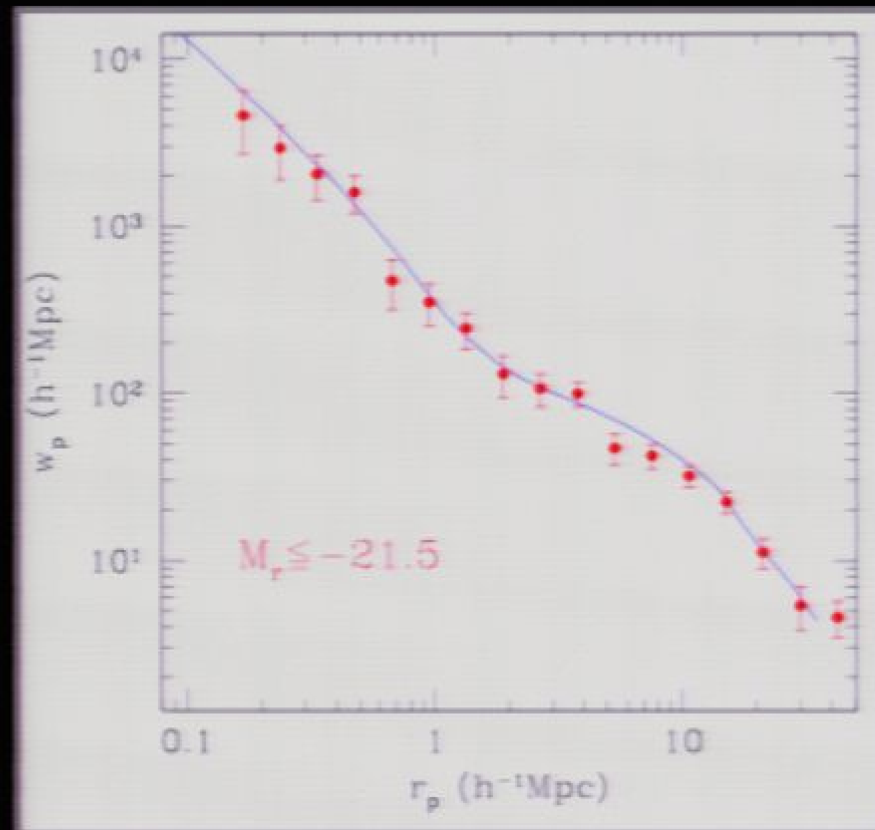
correlation function: HOD modeling





- consider $N_{RG}=N_{RG,cen}+N_{RG,sat}$
- $N_{RG,cen}=1$ if$(M \geq M_{min})$
- $N_{RG,sat}=(M/M_1)^{\alpha}$
- HOD modeling suggests RGs are hosted by halos more massive than 10^{13} M_{sun} (consistent with lensing results from Mandelbaum et al 08)
- weak halo mass dependence (α close to 0)

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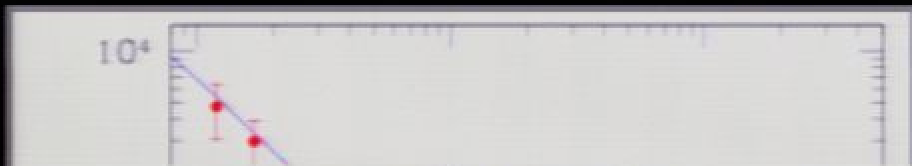

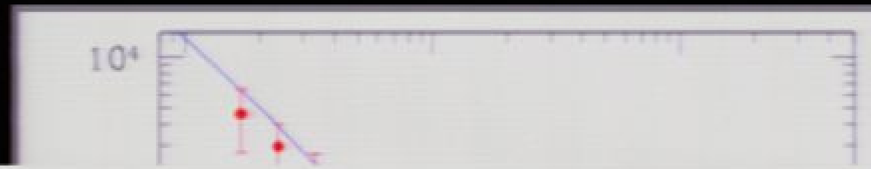

$$P_{\rm gal}(k) = P^{1h}_{\rm gal}(k) + P^{2h}_{\rm gal}(k), \quad \text{where}$$

$$P^{1h}_{\rm gal}(k) = \int {\rm d}m\, n(m)\, \frac{\langle N_{\rm gal}(N_{\rm gal}-1)|m\rangle}{\bar{n}^2_{\rm gal}}\, |u_{\rm gal}(k|m)|^p\ ,$$

$$P^{2h}_{\rm gal}(k) \approx P^{\rm lin}(k) \left[\int {\rm d}m\, n(m)\, b_1(m)\, \frac{\langle N_{\rm gal}|m\rangle}{\bar{n}_{\rm gal}}\, u_{\rm gal}(k|m)\right]^2 .$$

Here,

$$\bar{n}_{\rm gal} = \int {\rm d}m\, n(m) \langle N_{\rm gal}|m\rangle$$

Cooray & Sheth (02)

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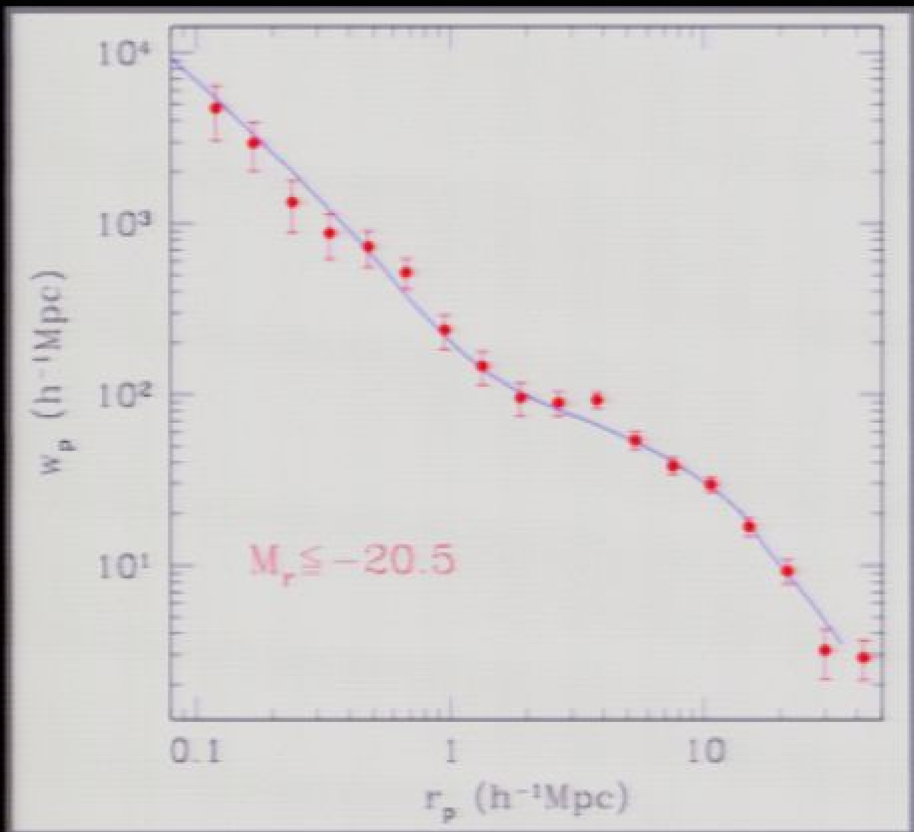

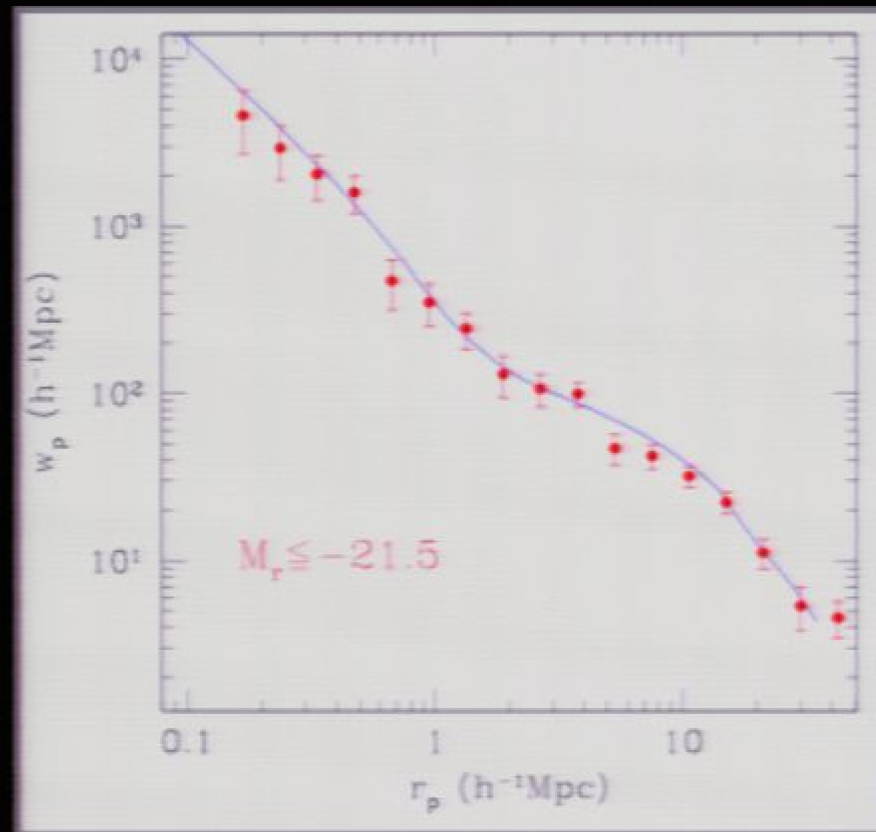

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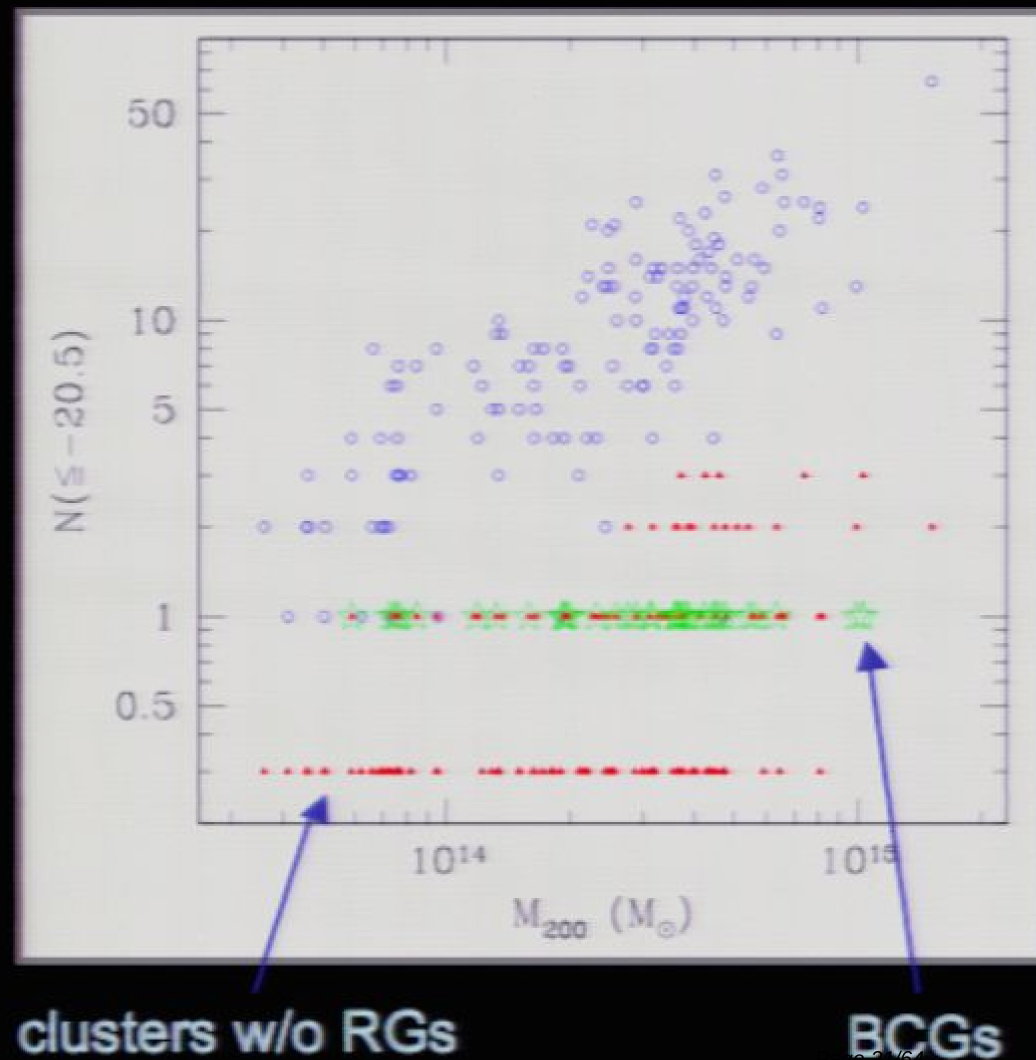
RGs in massive halos: halo occupation number

- count galaxies and RGs at $M_r \leq -20.5$ in 134 X-ray clusters from ROSAT all-sky survey
- number of galaxies goes as $M^{0.8}$
- occupation number of RGs not a strong function of cluster mass
- 1435 galaxies, 85 RGs (~6%)
- 62/134 (=46%) clusters host RGs
- among these, 34 have RL BCGs
- 44 clusters host only 1 RG, 20 of these are BCG
- 25% of BCGs are RL
- 3.9% of non-BCG galaxies are RL
- NOTE: 2.1% of galaxies are RL globally



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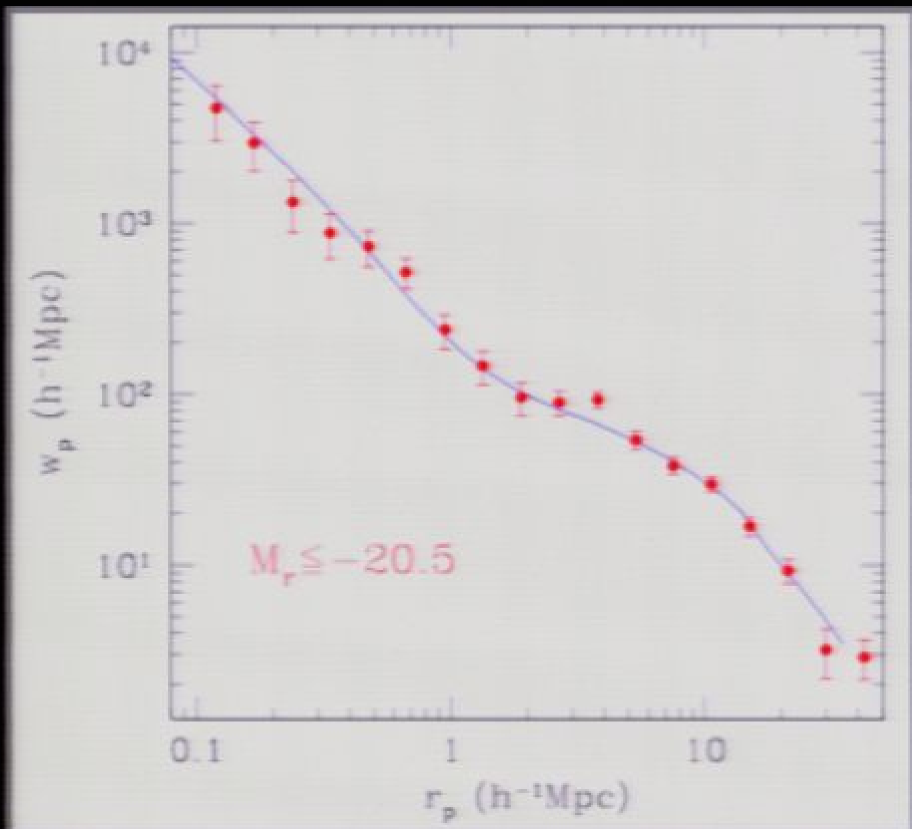

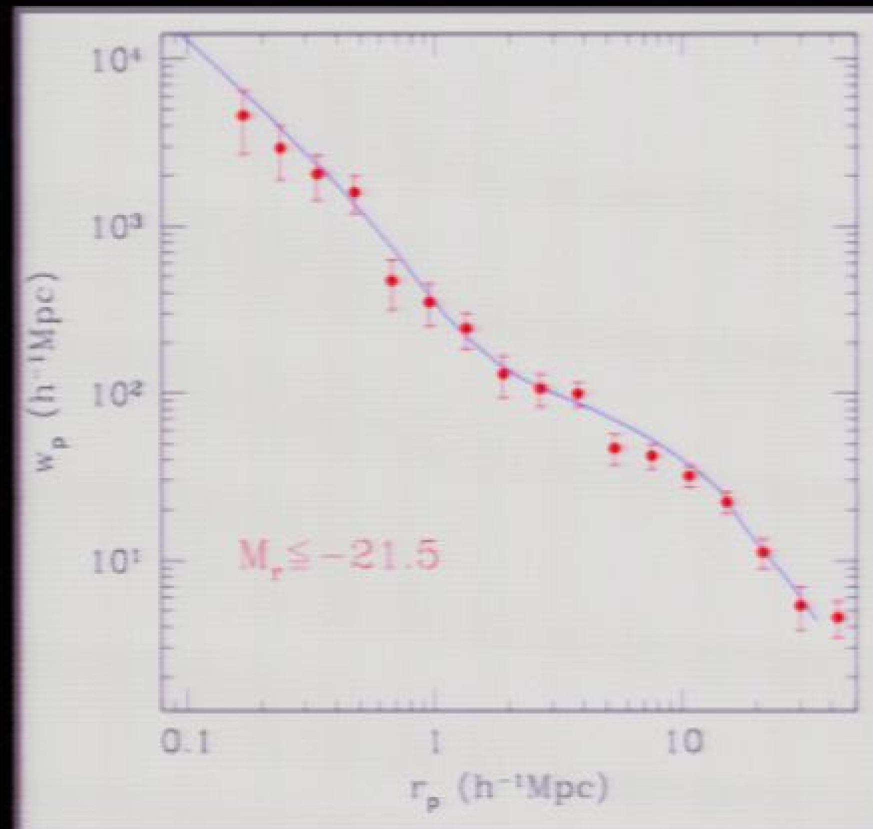

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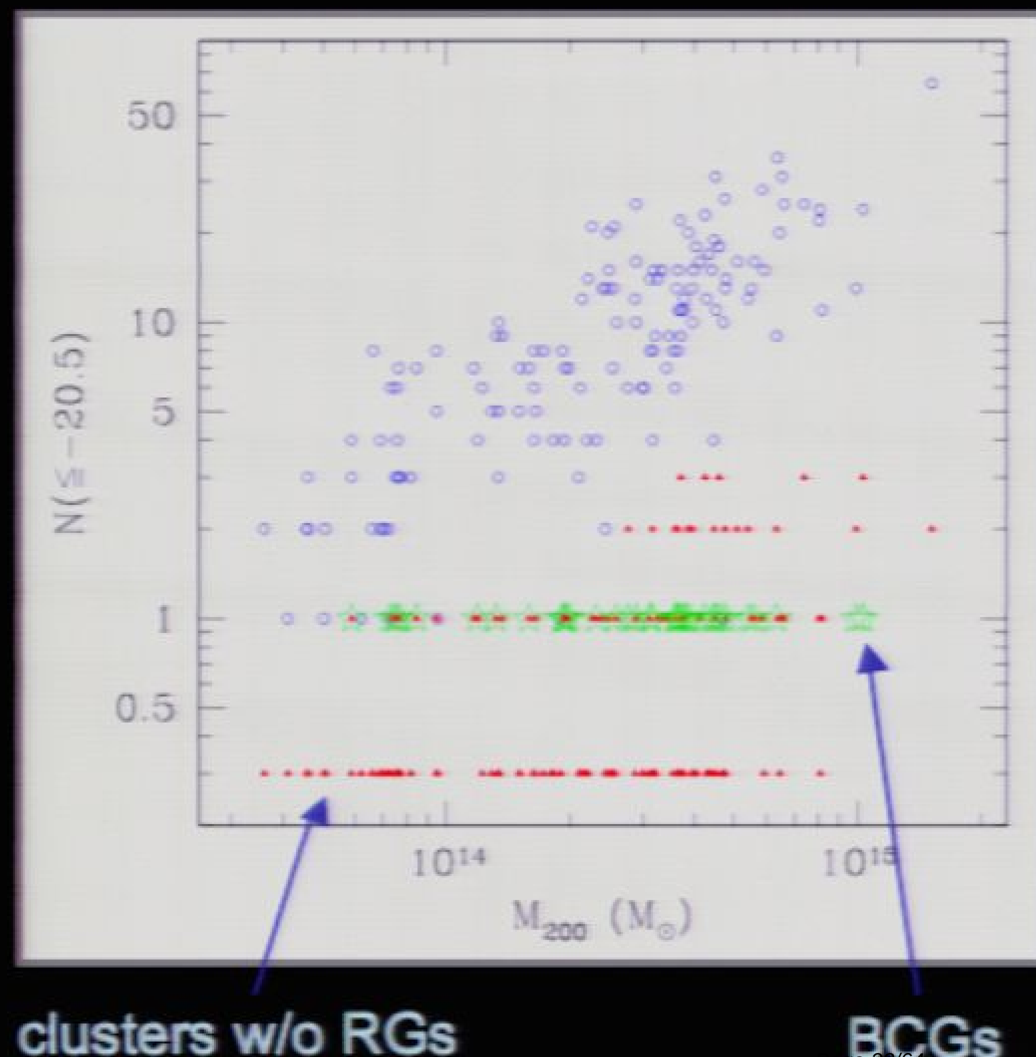
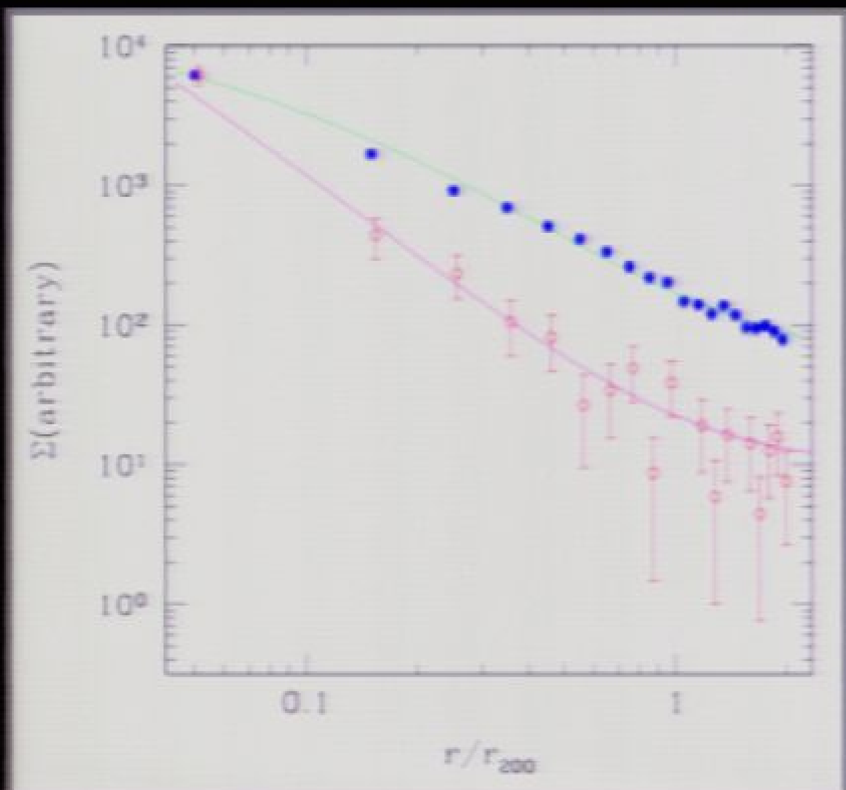
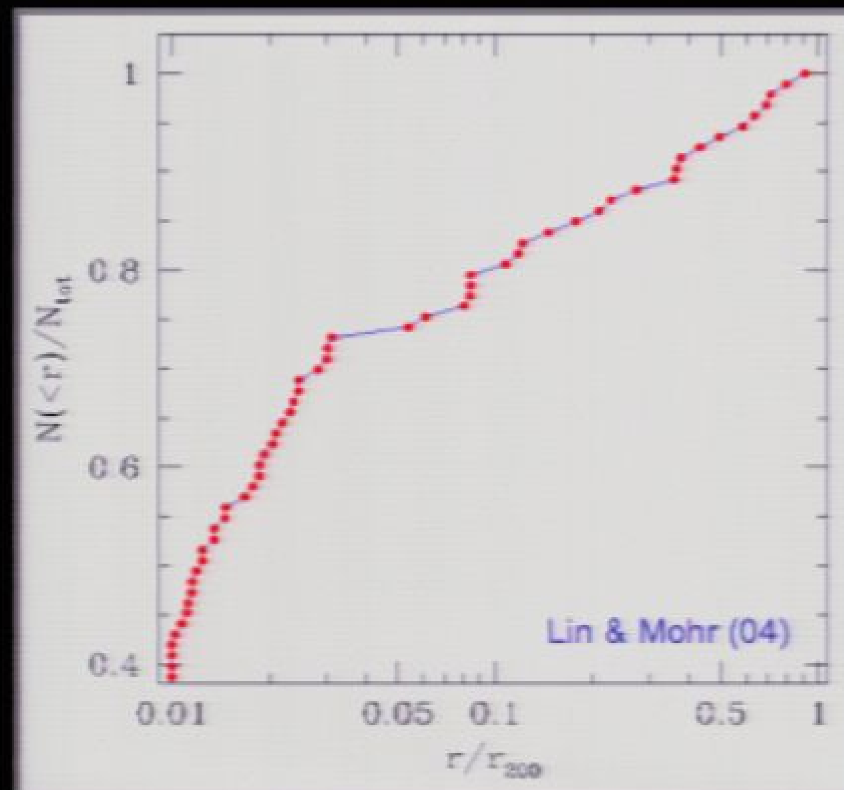


RGs in massive halos: spatial distribution

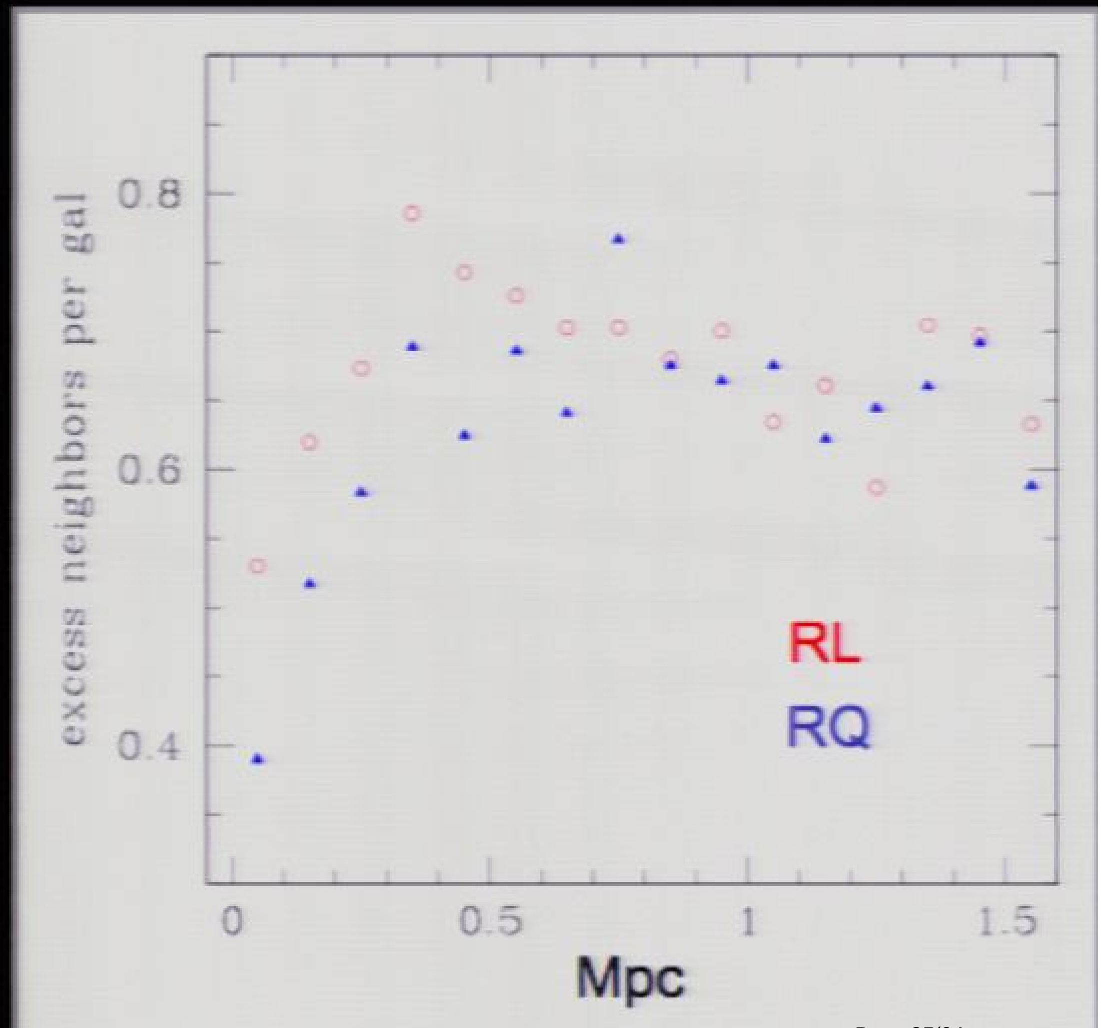




- RG distribution much more concentrated than galaxies
- in terms of NFW profile
  - galaxies: c~4
  - RGs: c~60
- being centrally located, BCGs have higher probability of being radio-active

RGs in dense regions: excess number of neighbors

- 1000 RGs, 1000 RQ galaxies matched to optical luminosity, apparent magnitude, and redshift
- count nearby objects out to 2 Mpc from SDSS photometric catalog, within $-23.5 \leq M_r \leq -20.5$
- within ~0.5 Mpc, RL galaxies always have higher number of neighbors than RQ ones



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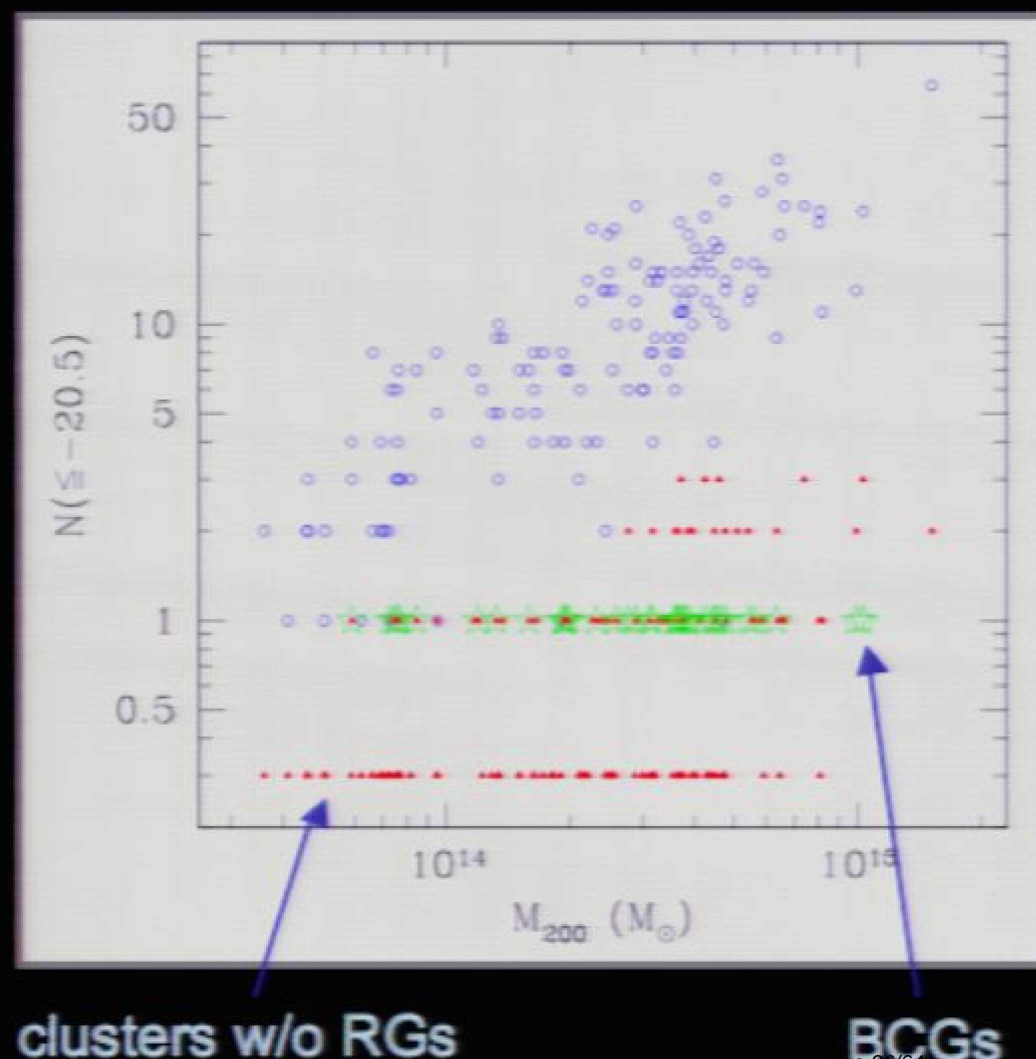

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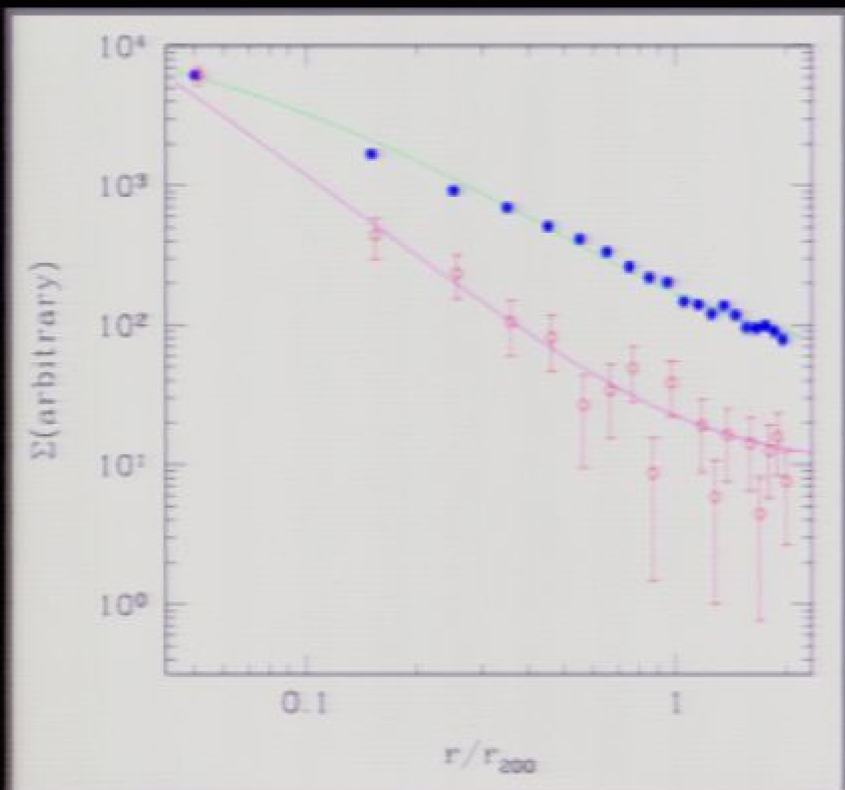

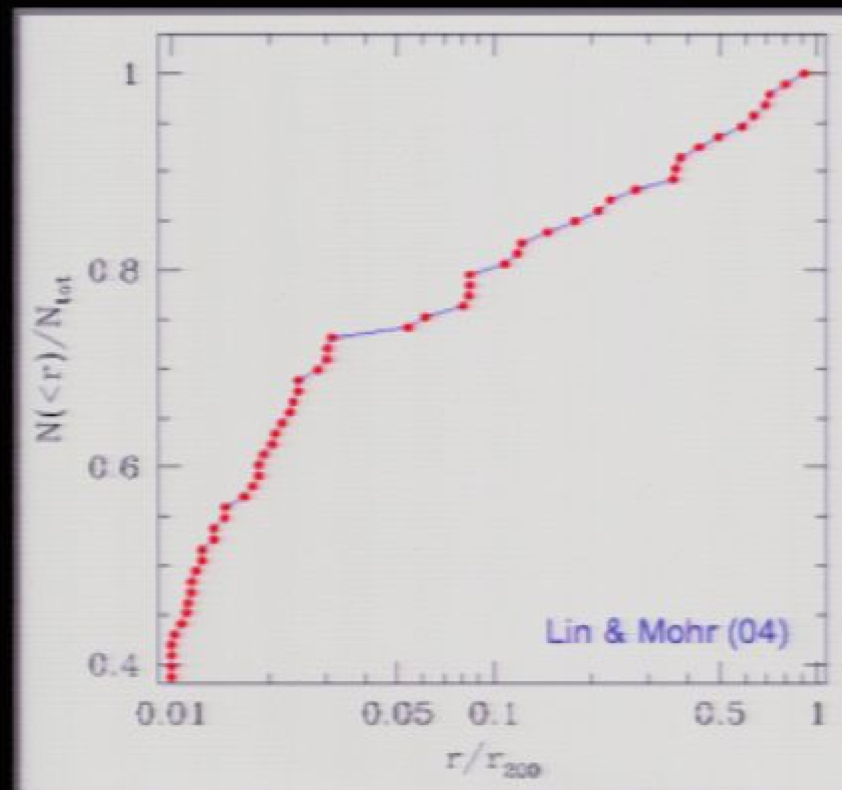

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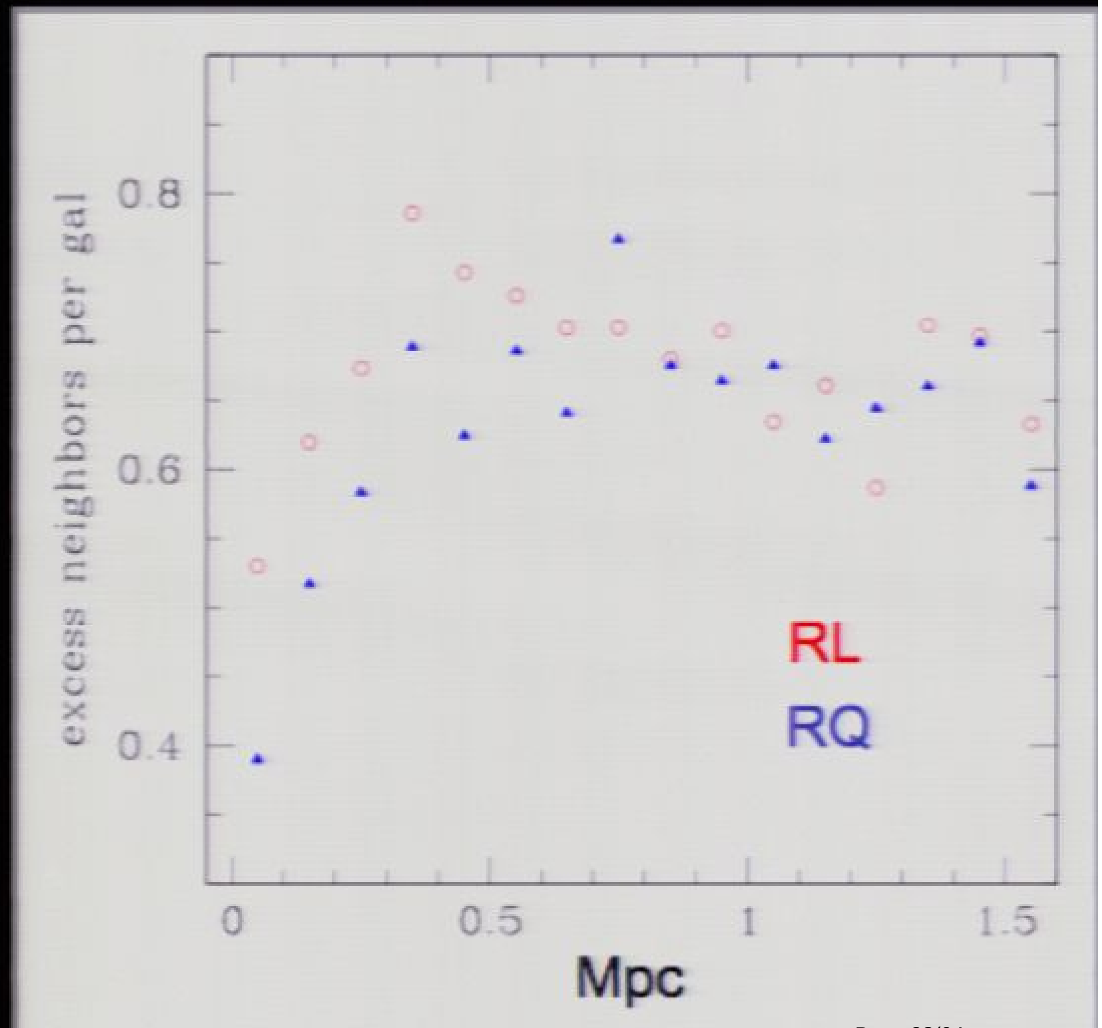

spectral energy distribution of radio sources in nearby clusters

- properties of RGs have been extensively studied at low frequencies (e.g., ≤10 GHz)
- SZE surveys typically carried out at much higher frequencies
- critical to know the SED or/and spectral index distribution (SID) to apply our knowledge from low frequency observations
- Bolton et al (2004) followed up 15 GHz-selected 9C sources at 1.4, 5, 22, 43 GHz, finding that SEDs can be complex ⇒ need more than 2 frequencies to infer the SED faithfully
  - these sources not restricted to cluster sources
  - no redshift info
- Coble et al (2007) studied SID of sources within cluster fields between 1.4 and 28.5 GHz (no cluster membership info)
- we tried to characterize the SED/SID based on 139 RGs in 110 clusters at z≤0.25 from 5 to 43 GHz (Lin, Partridge, et al 2009, ApJ 694, 992)

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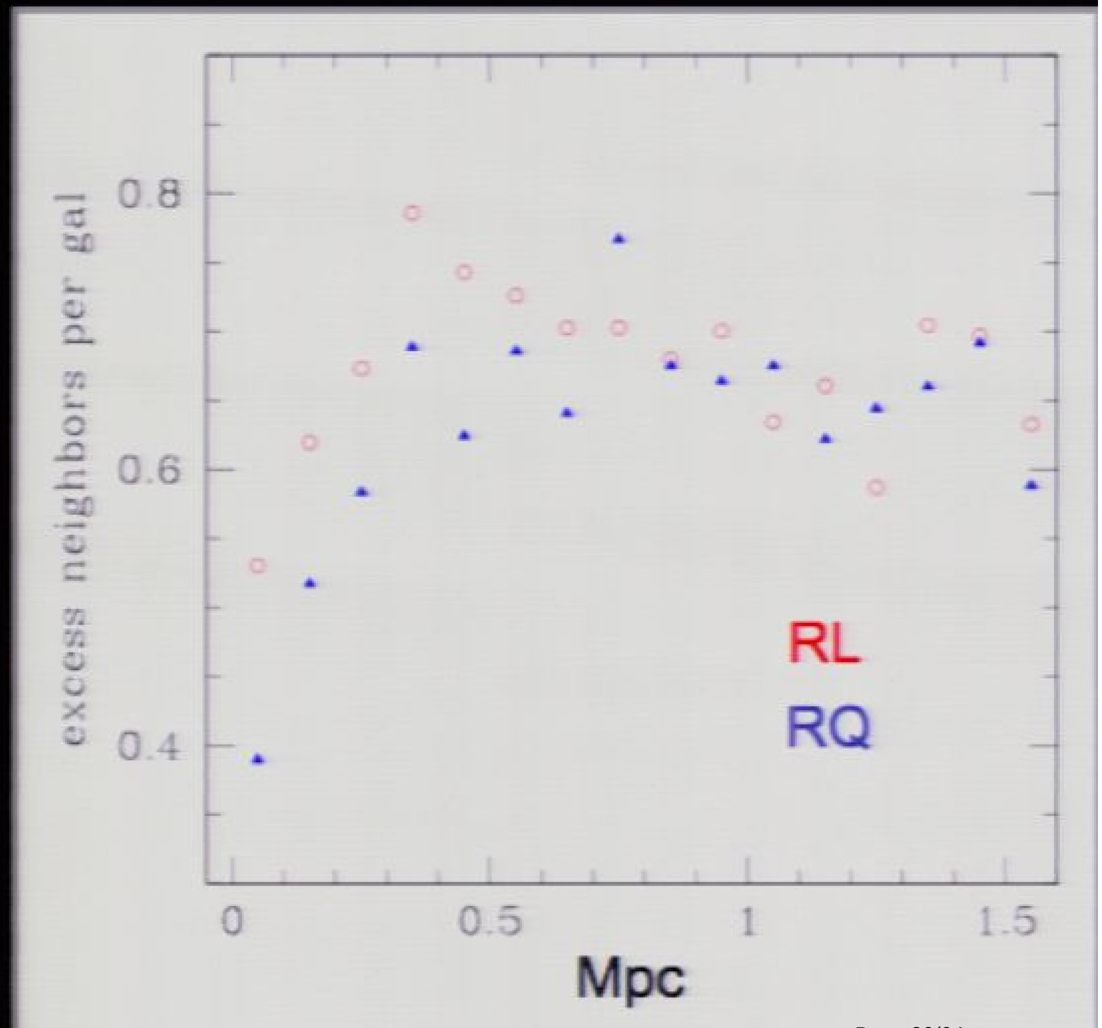

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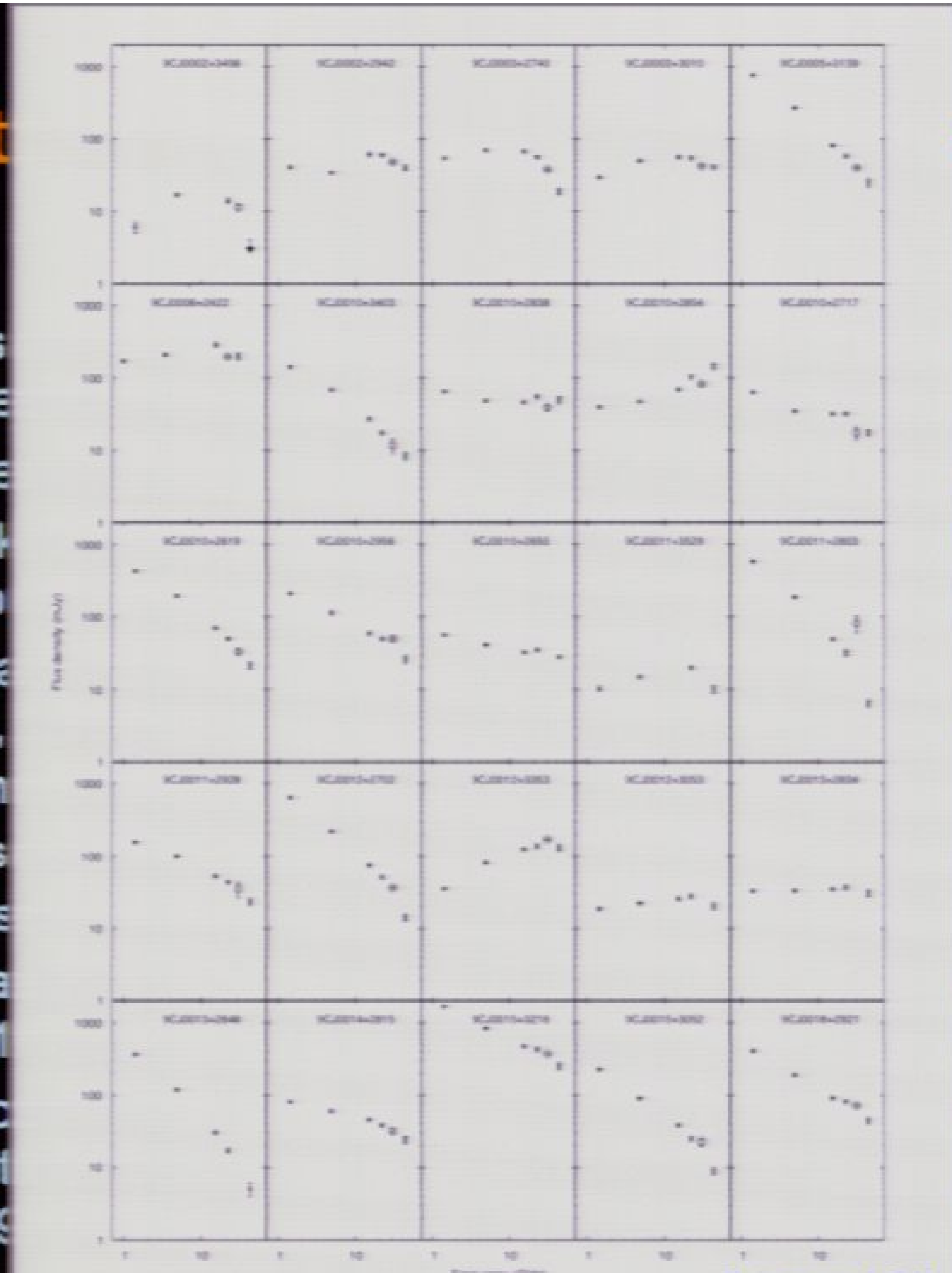

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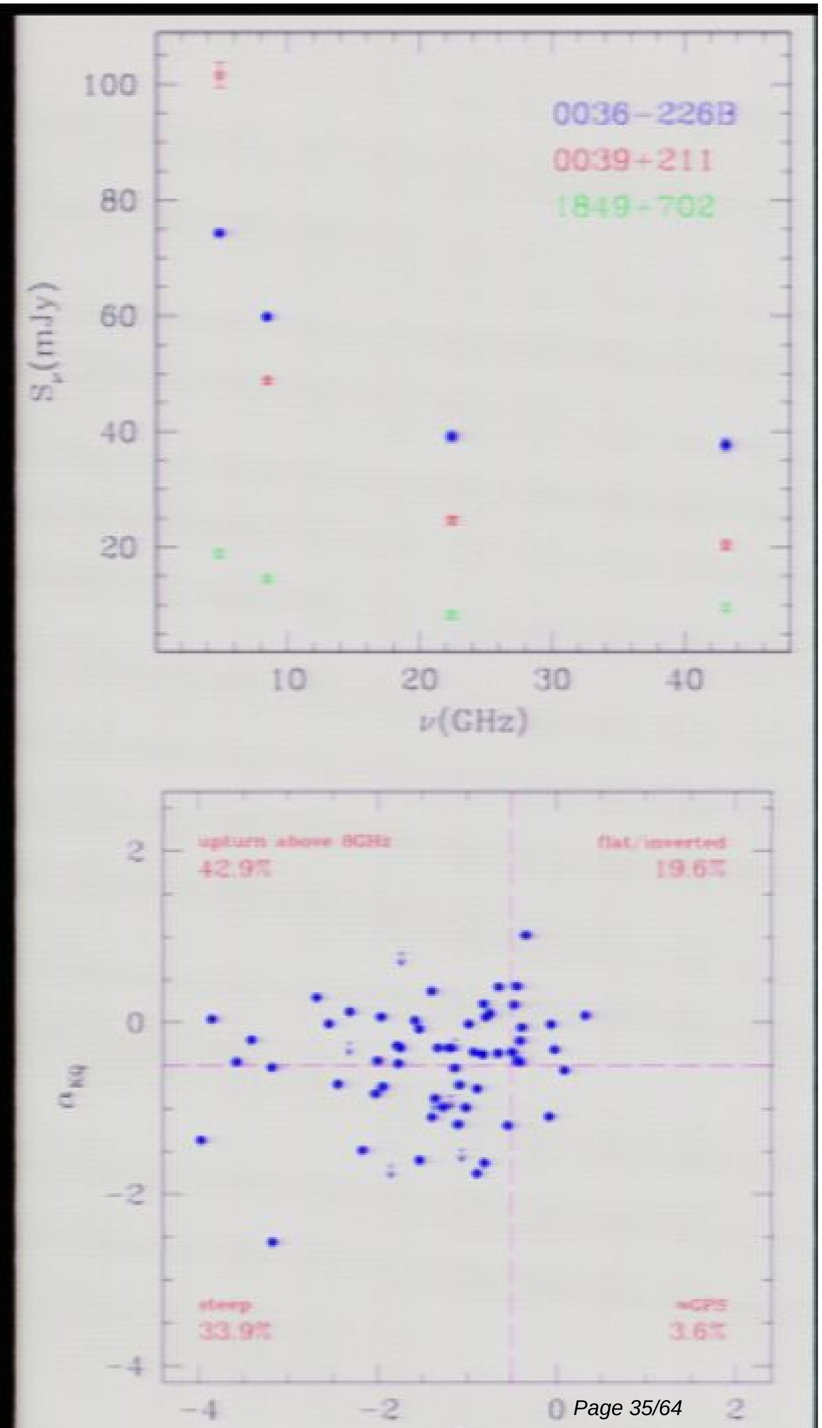
sample selection and observations

- Ledlow & Owen (1995,1996) conducted a 1.4 GHz survey of radio galaxies in ~400 Abell clusters at z≤0.25, with extensive redshift measurement for sources stronger than 10 mJy
- based on their radio galaxy catalog, we selected 139 sources in 110 clusters detected in X-rays (X-ray luminosity/temperature available)
- observations made October 2005 with VLA in DnC configuration
- frequencies 4.8, 8.5, 22.4 and 43.1 GHz (C, X, K, Q-bands) observed nearly simultaneously
- snapshot observations with rms flux density errors of 2 mJy, 0.5 mJy, 1.0 mjy and 0.8 mJy, respectively
- resolution roughly 8″x13″, 4″x8″, 2″x3″ and 2″x3″ in four bands
- flux unavoidably resolved out at high frequencies; in general, spectral indices would be lower limits (could be "flatter")
- convolved 43 GHz images with elliptical gaussian profile to match resolution at 22 GHz ("tapering"), for better measurement of α_{KQ}
- no tapering for other frequencies

spectral shape of RGs

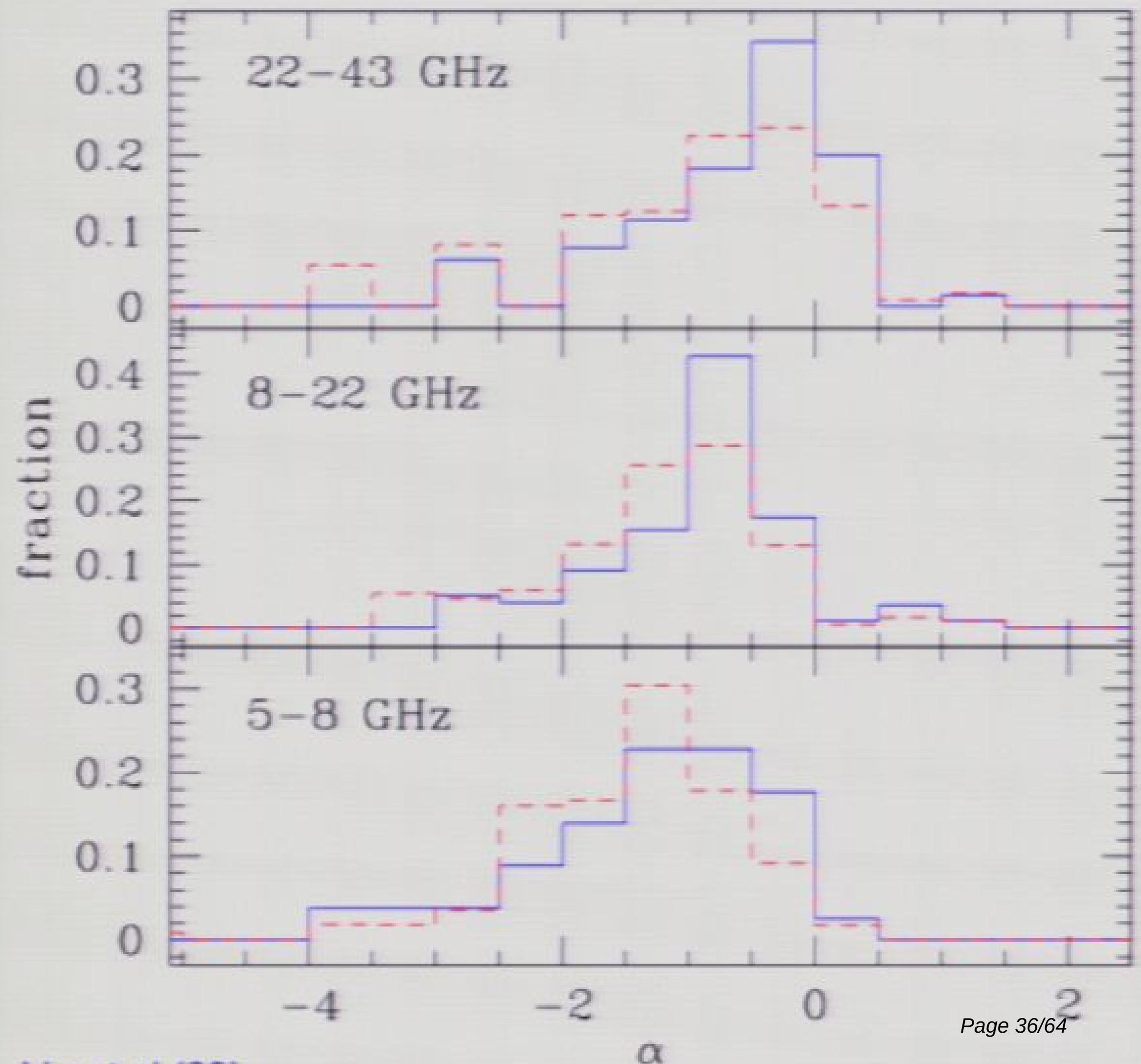
- 136 galaxies detected in at least one band
- 111 galaxies (140 components) detected in 3 or all bands
- ~86% of these have steep spectrum ($S \propto \nu^{\alpha}$, $\alpha \leq -0.5$) at lowest frequencies
- 57 sources/components detected in all bands are barely resolved or unresolved, or unresolved cores of extended sources; 62% of these sources have $\alpha > -0.5$ in 22-43 GHz
- the actual flux at 43 GHz is typically ~2x higher (with large scatter) than would have been found by extrapolating the 4.8-8.5 GHz spectra



Lin et al (09)

spectral index distribution

- solid histogram: core/point-like sources
- dashed histogram: all sources
- spectral indices α_{CX} and α_{XK} would be lower limits



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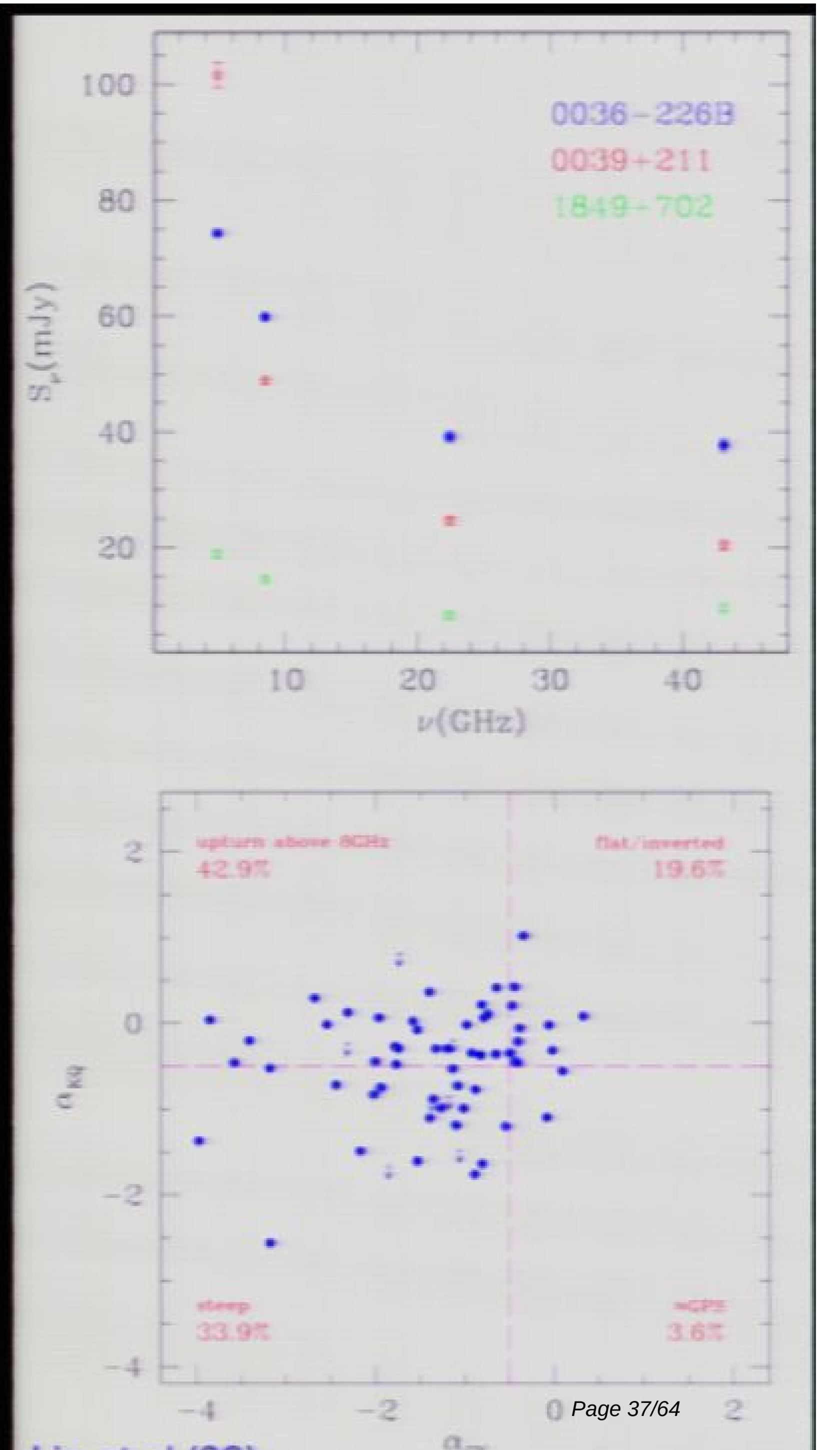

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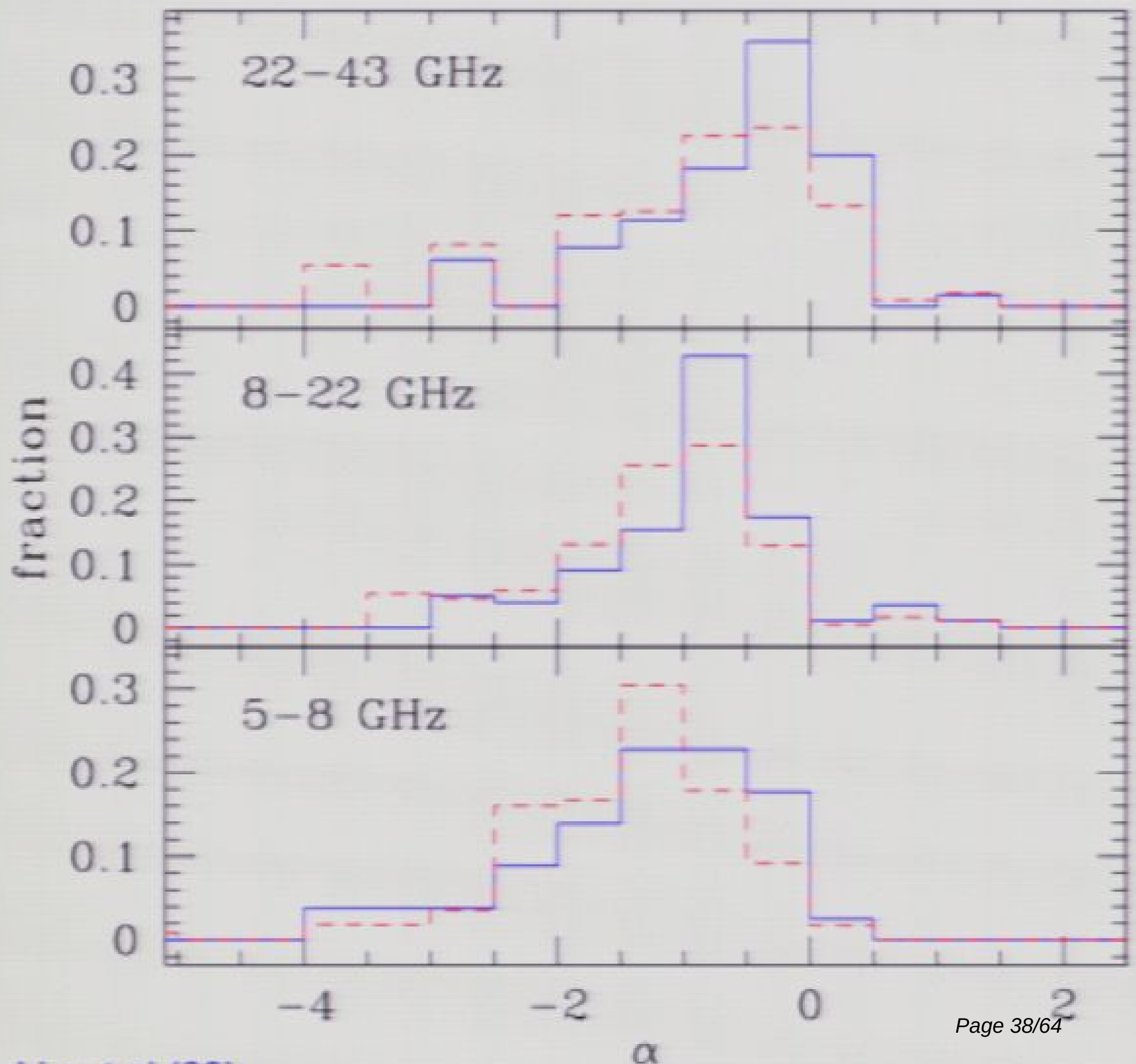
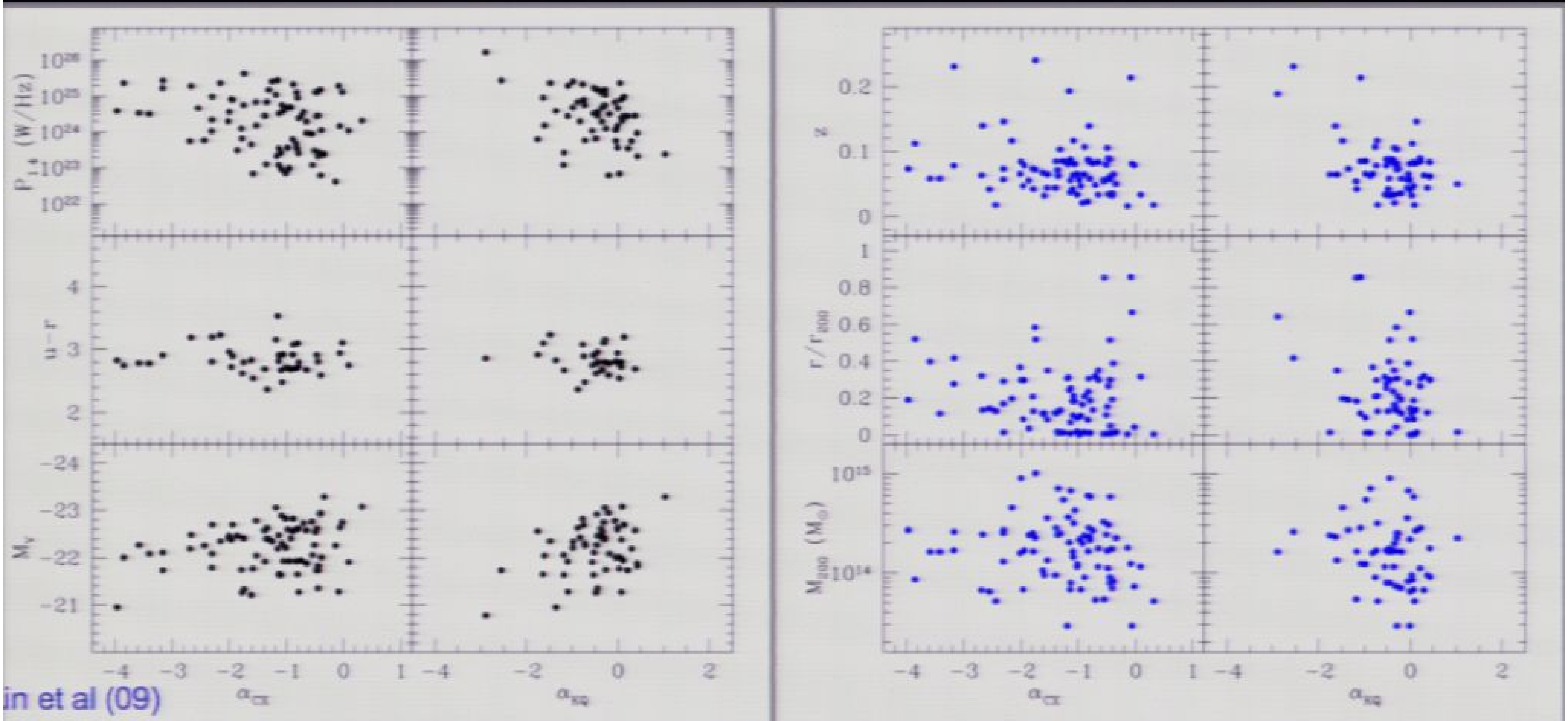


Lin et al (09)

SID vs host galaxy/cluster properties



- no obvious correlation with optical luminosity, color, radio power of host galaxies
- no obvious correlation with redshift and mass of host clusters, and cluster-centric distance

SED of intermediate-z cluster RGs

- we have also obtained VLA data at 5, 8, 22, and 43 GHz for a smaller sample of RGs (selected at 1.4 GHz) in 10 clusters at $0.3 \leq z \leq 0.8$
- data reduced, analysis on-going
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a phenomenological model of powerful radio sources

- many models in the literature (e.g., Condon 84, Dunlop & Peacock 90, Toffolatti et al 98, Jackson & Wall 99, Willott et al 01, de Zotti et al 05, Wilman et al 08)
- goals
  - constrain the cosmological evolution of RGs in WMAP cosmology
  - easy way to create realistic mock catalogs of radio-loud AGNs in mm-wave surveys
- features of the model
  - relationship between halos and radio sources built-in
  - halos populated with sources in a Monte-Carlo fashion
  - fits the source counts from 0.15 to 150 GHz, radio LF to z~2, clustering properties of radio sources
- caveats
  - no sources beyond z=3 (may bias the inferred evolution)
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construction of model

- populate dark matter halos with radio sources
  - N(M) and its redshift evolution
  - spatial distribution
  - spectral shape
- dark matter halo and SZE catalogs generated from light-cone simulation by Paul Bode and Hy Trac
- two classes of radio-loud AGNs
  - low-power population, mild redshift evolution (≈FRI)
  - high-power population, strong redshift evolution (≈FRII)
- model SED of extended and core components similarly to Wilman et al (08)
  - extended/lobe component: $S \propto \nu^{-0.8}$
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  - relativistic beaming model for core-to-lobe flux ratio

image credit: Leahy, Bridle, Strom

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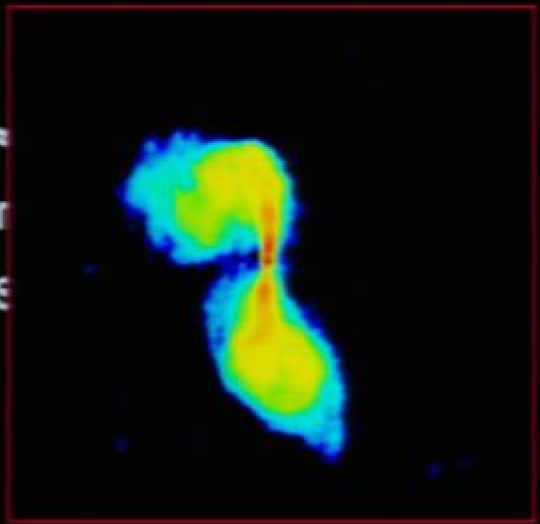

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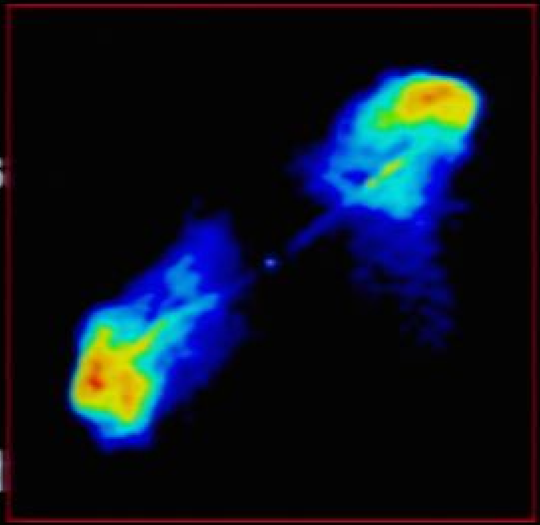

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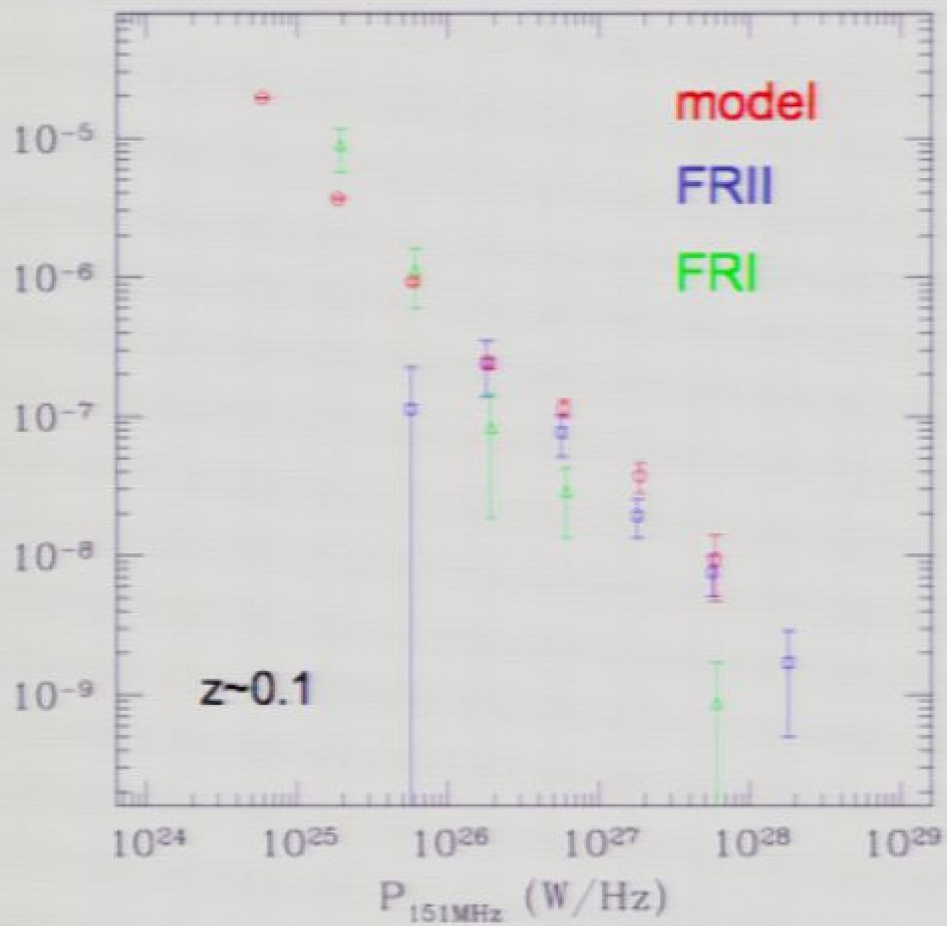
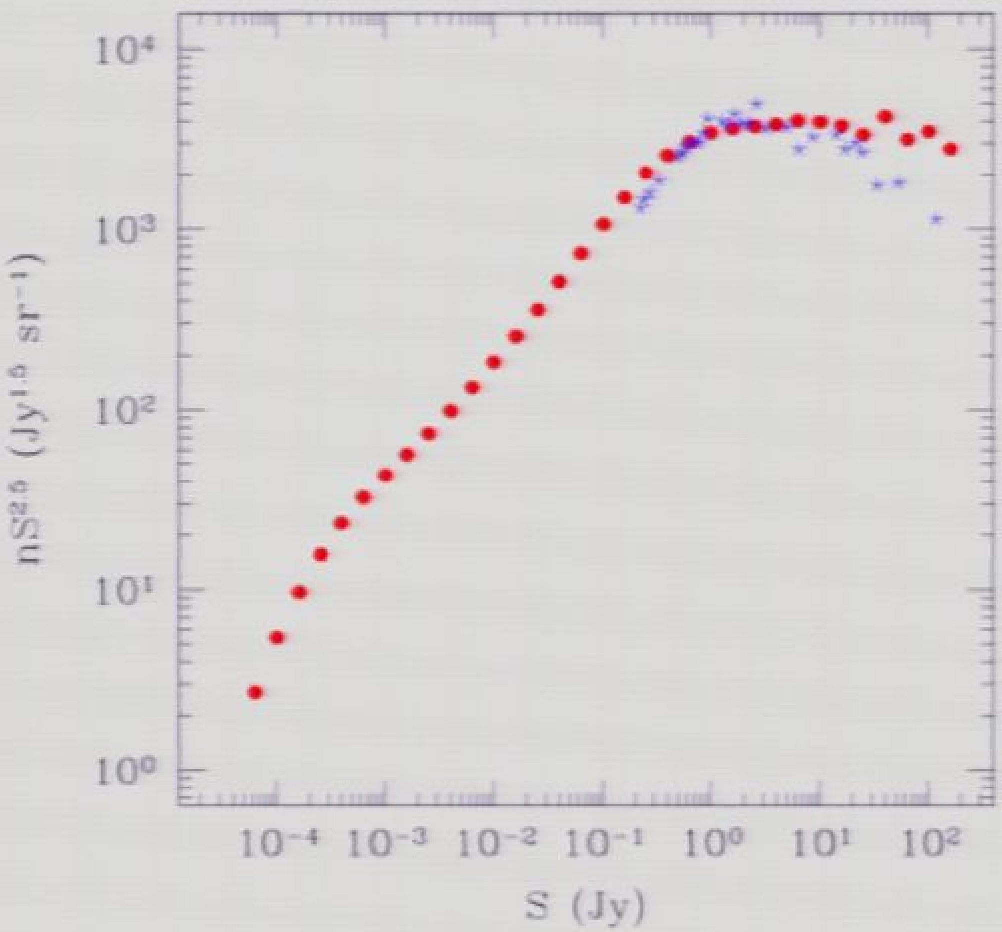
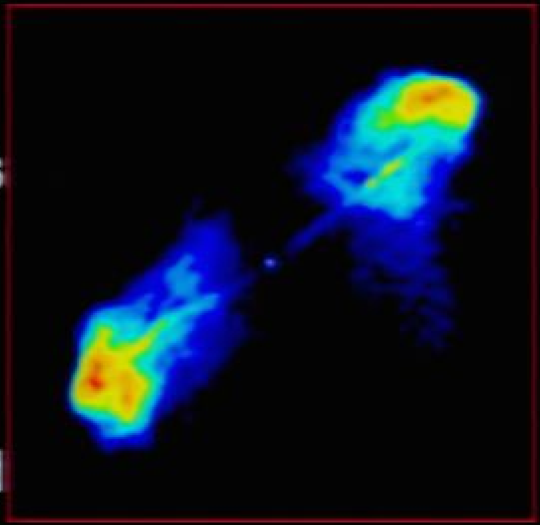
RLF and source count at 151 MHz





- draw radio luminosity from an assumed luminosity distribution
- tune HOD parameters so that 151 MHz RLF at z~0.1 is reproduced
- adjust density evolution to fit source count and RLFs at z~1 & 2 at 151 MHz
- set average SED of core component to reproduce the source counts at high-ν

construction of model



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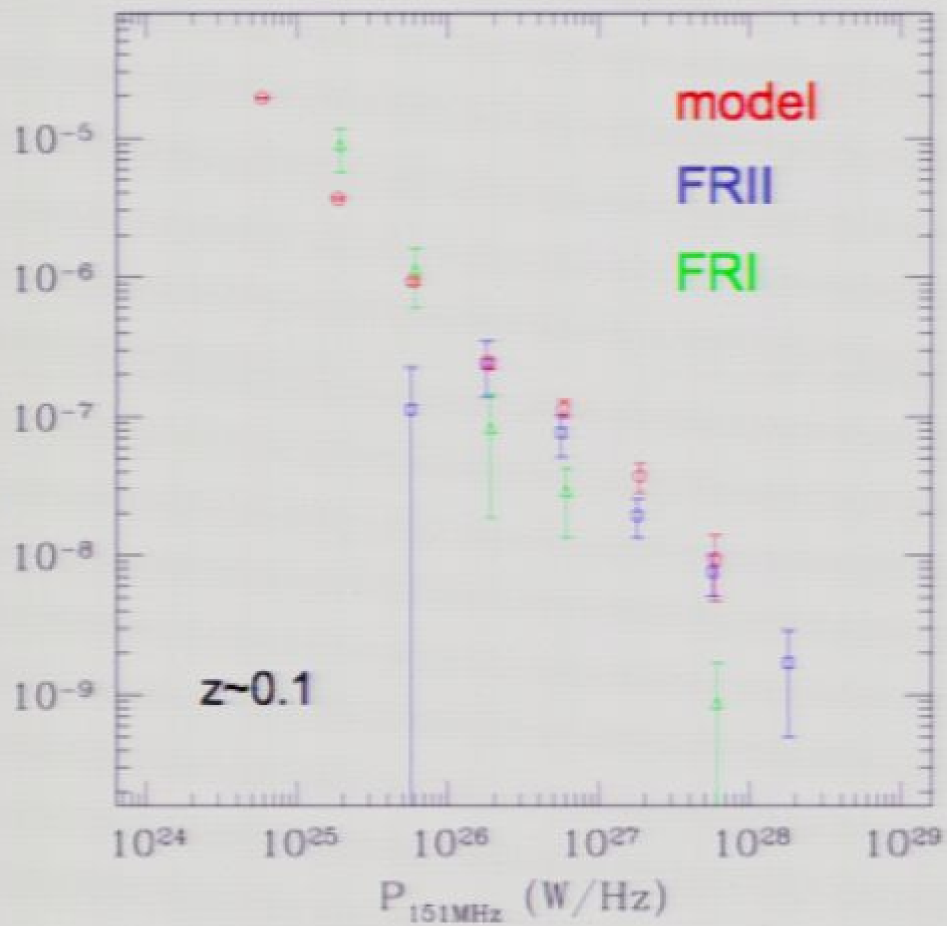

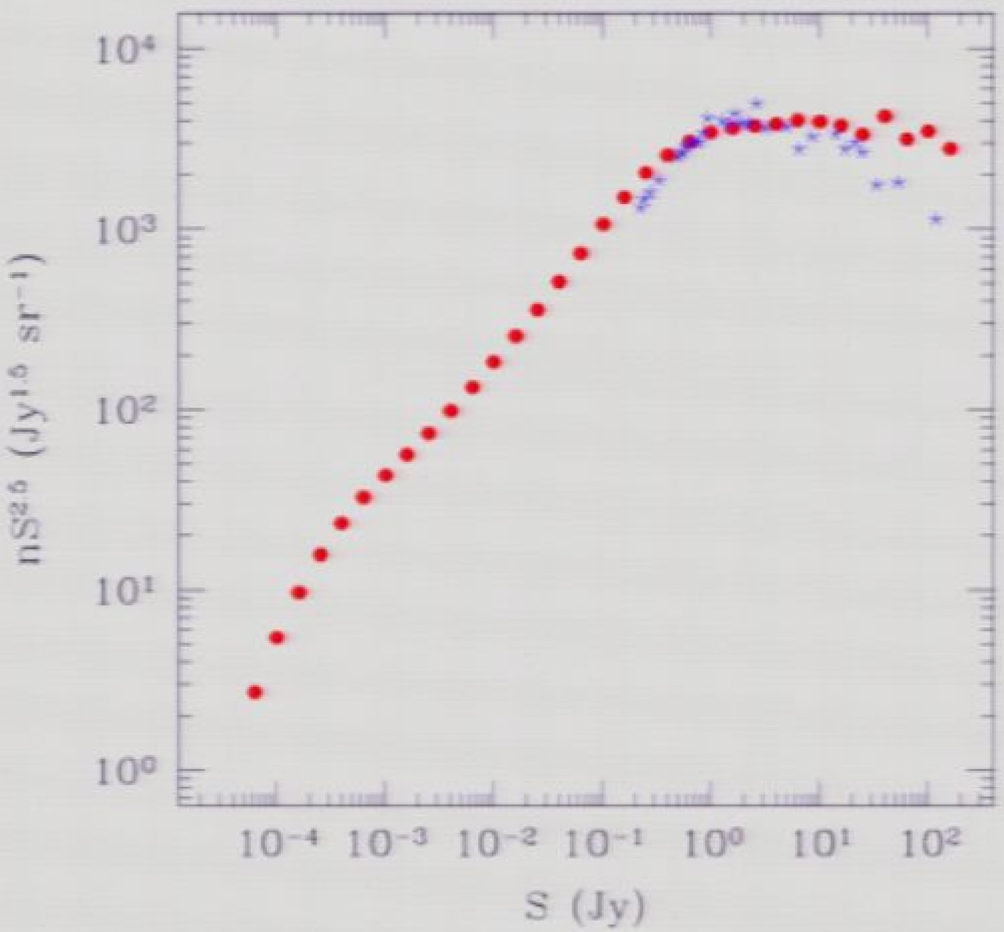

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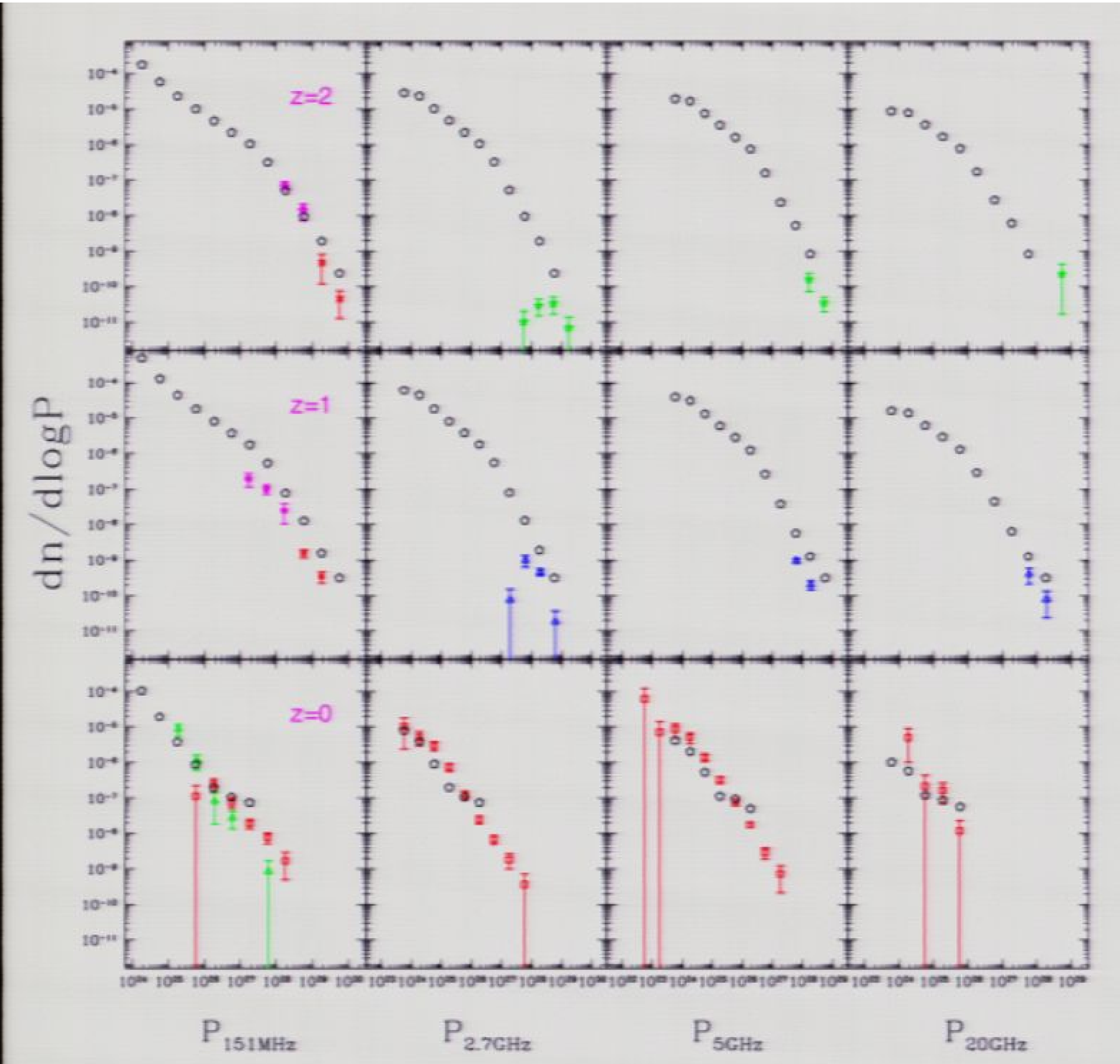
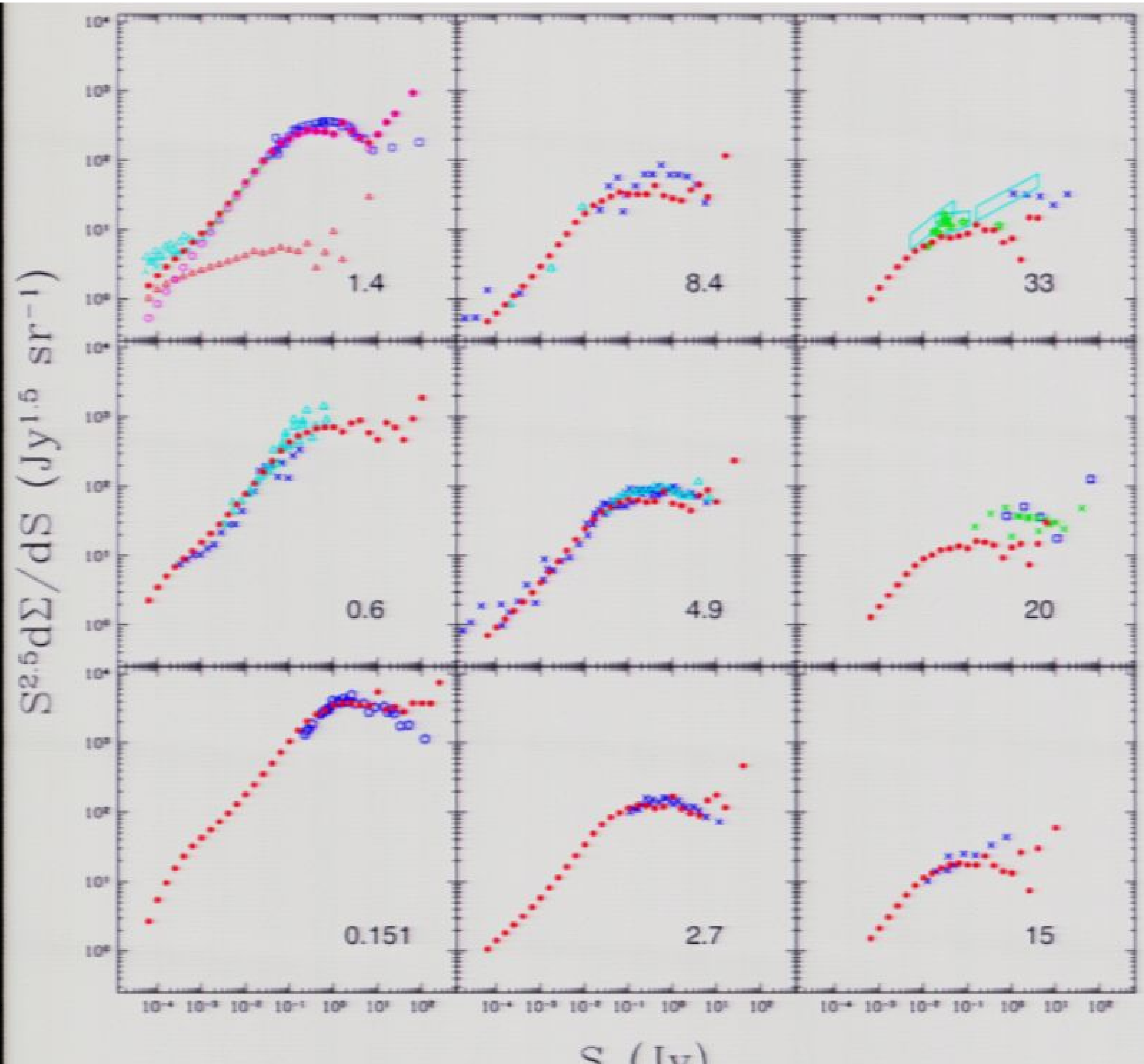

z=2
z=1
z=0
dn/dlogP
P151MHz
P2.7GHz
P5GHz
P20GHz


$S^{2.5}d\Sigma/dS$ ($Jy^{1.5}$ sr^{-1})
1.4
8.4
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0.6
4.9
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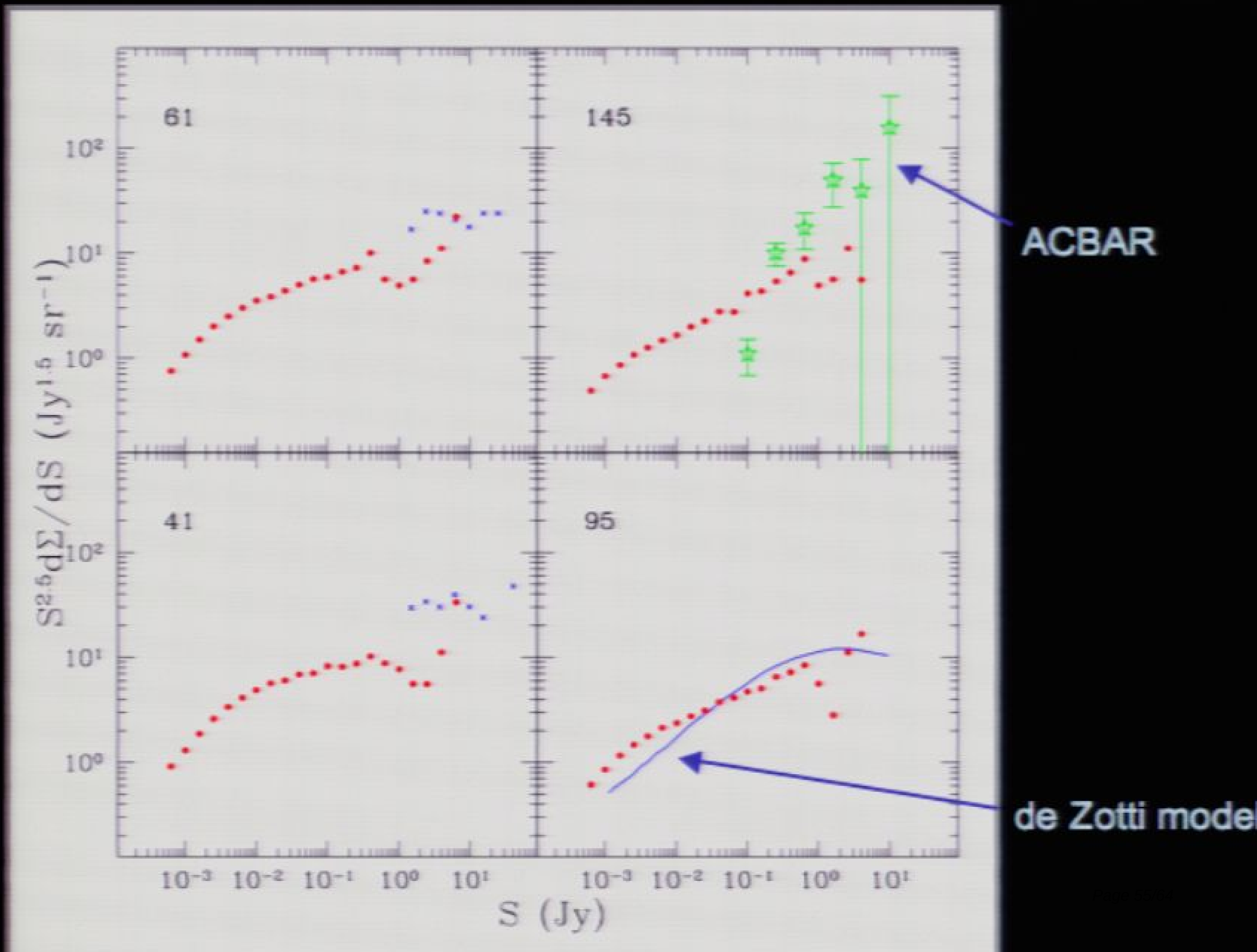
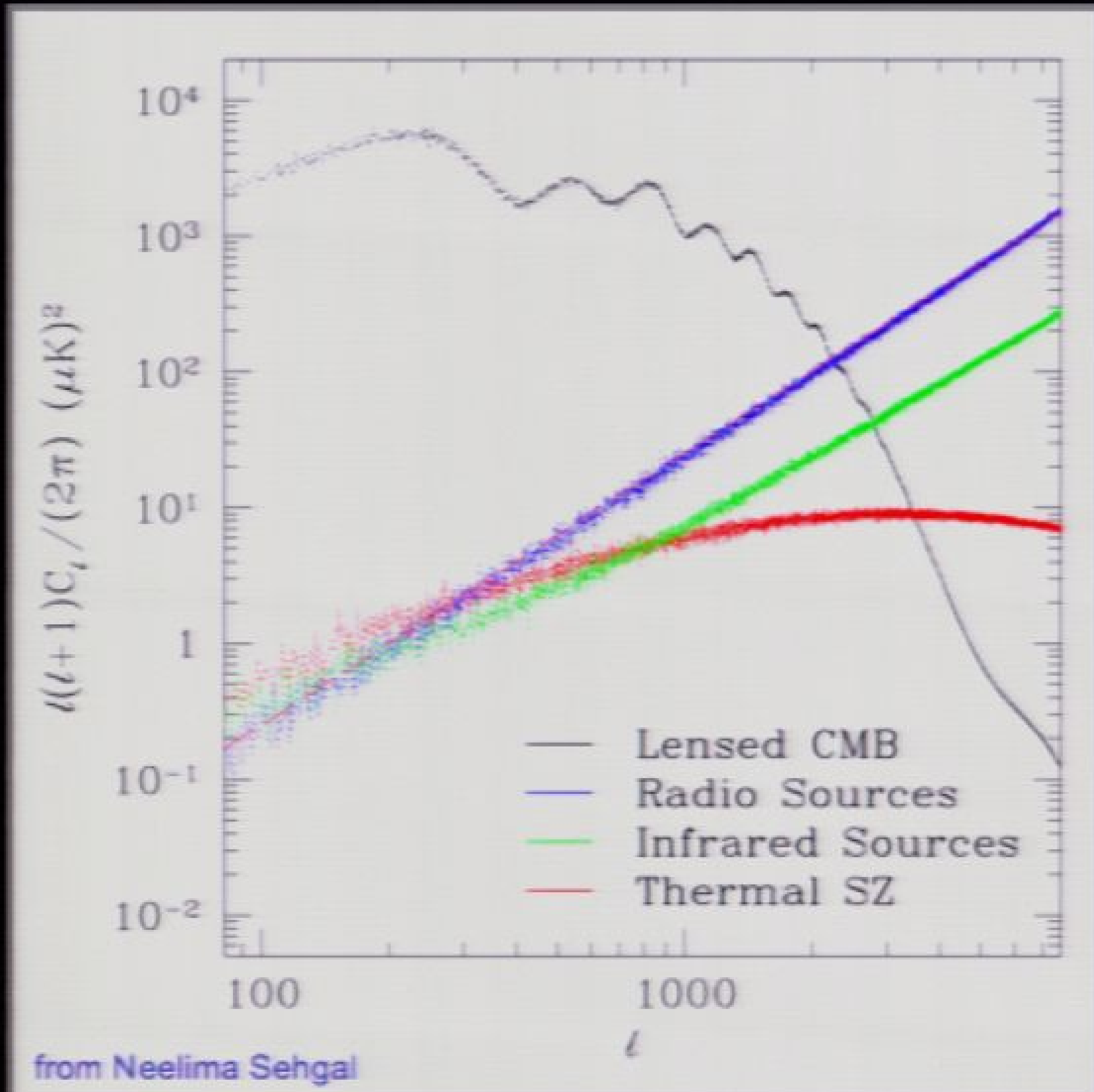
15
S (Jy)

high frequency source counts



power spectrum of model sources

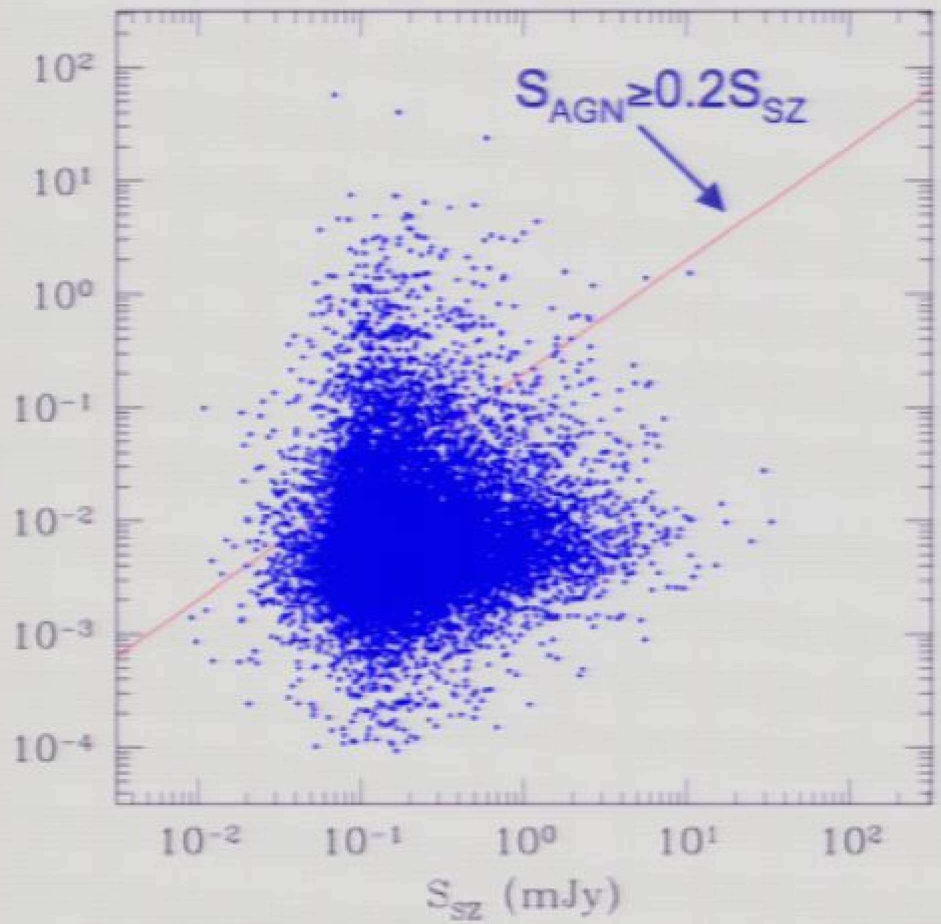


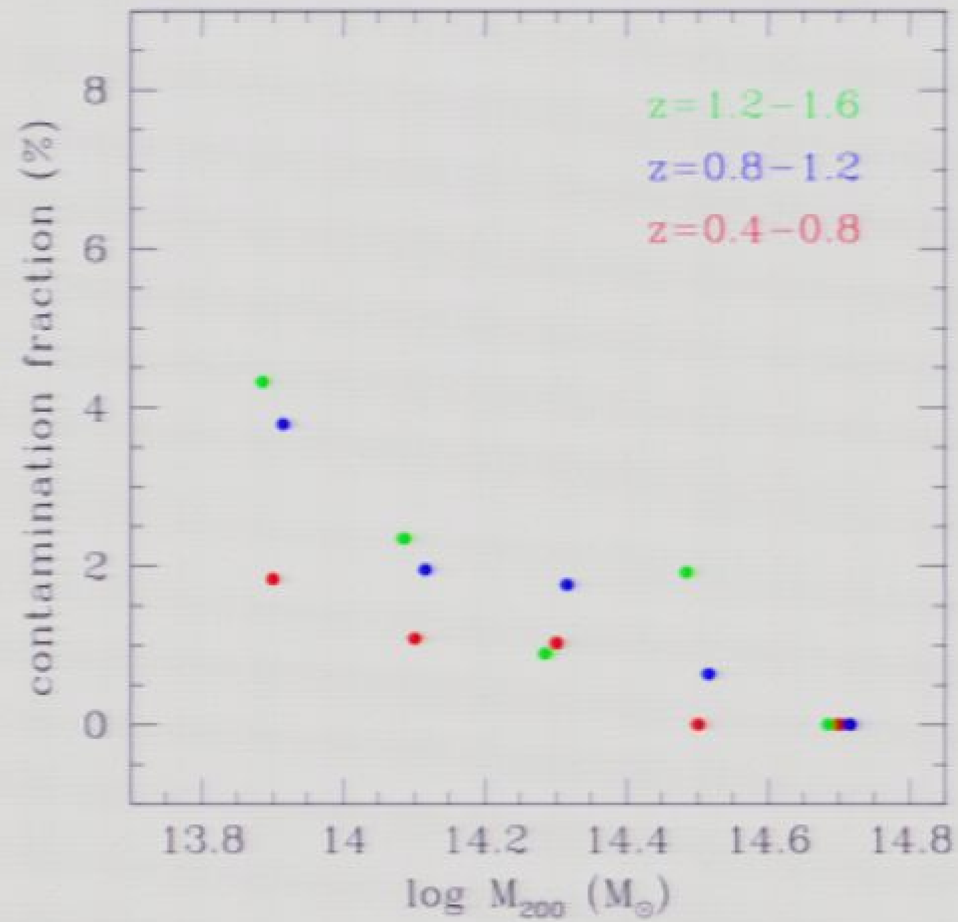
- power spectrum at 148 GHz agrees with the Toffolatti/de Zotti model (x0.64)

model parameters

- best parameters may not be unique
- limitation imposed by halo catalog ($z \leq 3$, halo mass limit)
- for FRII
  - HOD: $N = 0.015(M/3\times10^{15})^{0.1}$; NFW profile with $c=5$
  - density evolution: asymmetric gaussian peaking at $z=1.3$, with $\sigma_{low}=0.4$ and $\sigma_{high}=0.7 \Rightarrow$ 200x increase in density at $z=1.3$
- for FRI
  - HOD: $N=(M/4\times10^{13})^{0.1}$; NFW profile with $c=30$
  - density evolution: at $z \leq 0.8$, $\propto (1+z)^3$; constant afterwards

contamination of SZE signal from radio sources





- halos selected at z=0.9-1, in one 1260 deg^2 patch of the sky
- all halos in 1260 deg^2, contaminated to 20% or more
- see similar forecast in Lin et al (09)

summary

- RGs in the local universe
  - given optical luminosity and color, RGs are more strongly clustered than the corresponding RQ galaxy sample
  - large scale clustering implies hosts are group or cluster-sized halos
  - RGs very centrally concentrated towards halo center
  - ingredients for RL AGN phenomenon
    - dense environment
    - presence of intracluster/intragroup gas: confining pressure
    - low level supply of gas: what's the source?
- SED of cluster RGs
  - spectra are generally complex
  - SID/SED seem to be independent of host galaxy/cluster properties
- model for cosmological evolution of powerful RGs
  - powerful FRII sources experience 200x increase in density at z~1.3
  - not much constraints on FRI evolution
  - low contamination (<5%) of SZE from radio sources expected

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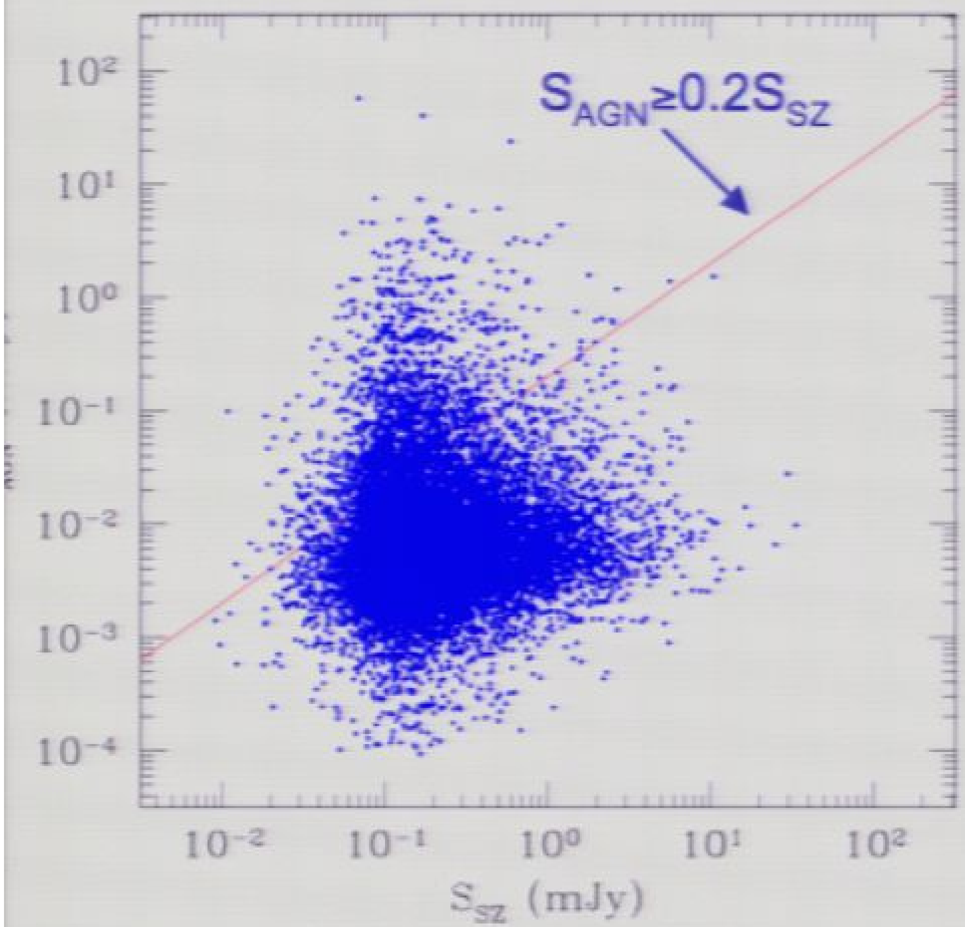

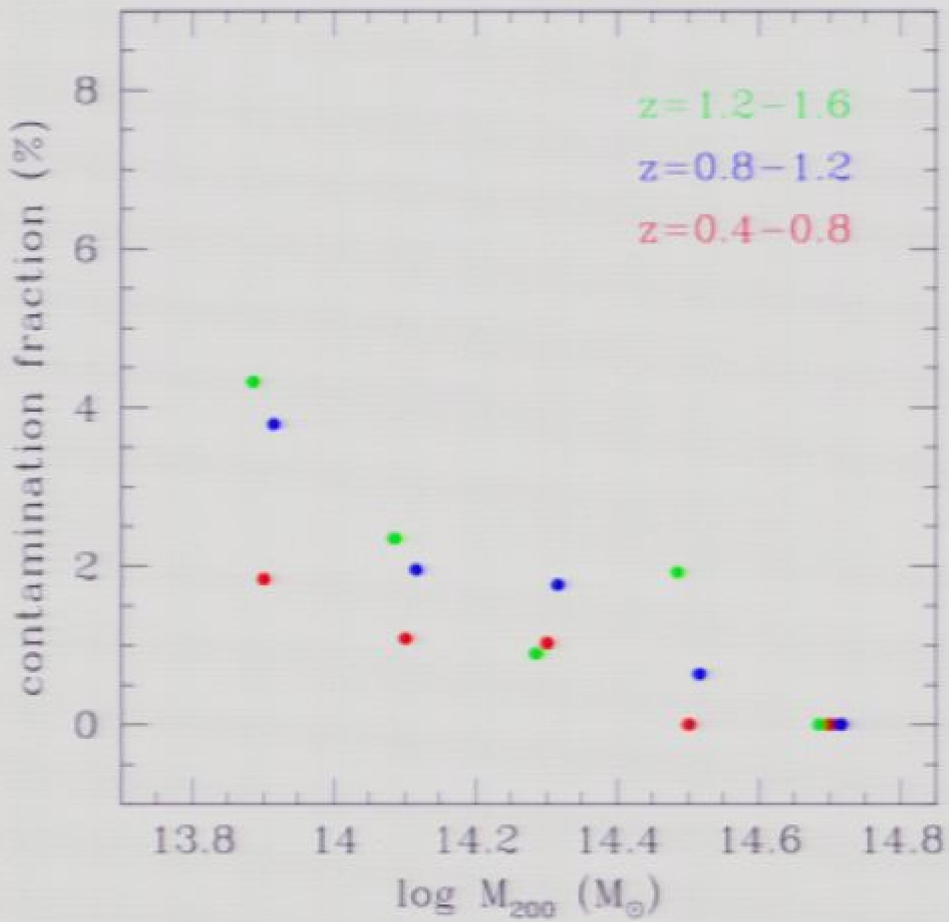

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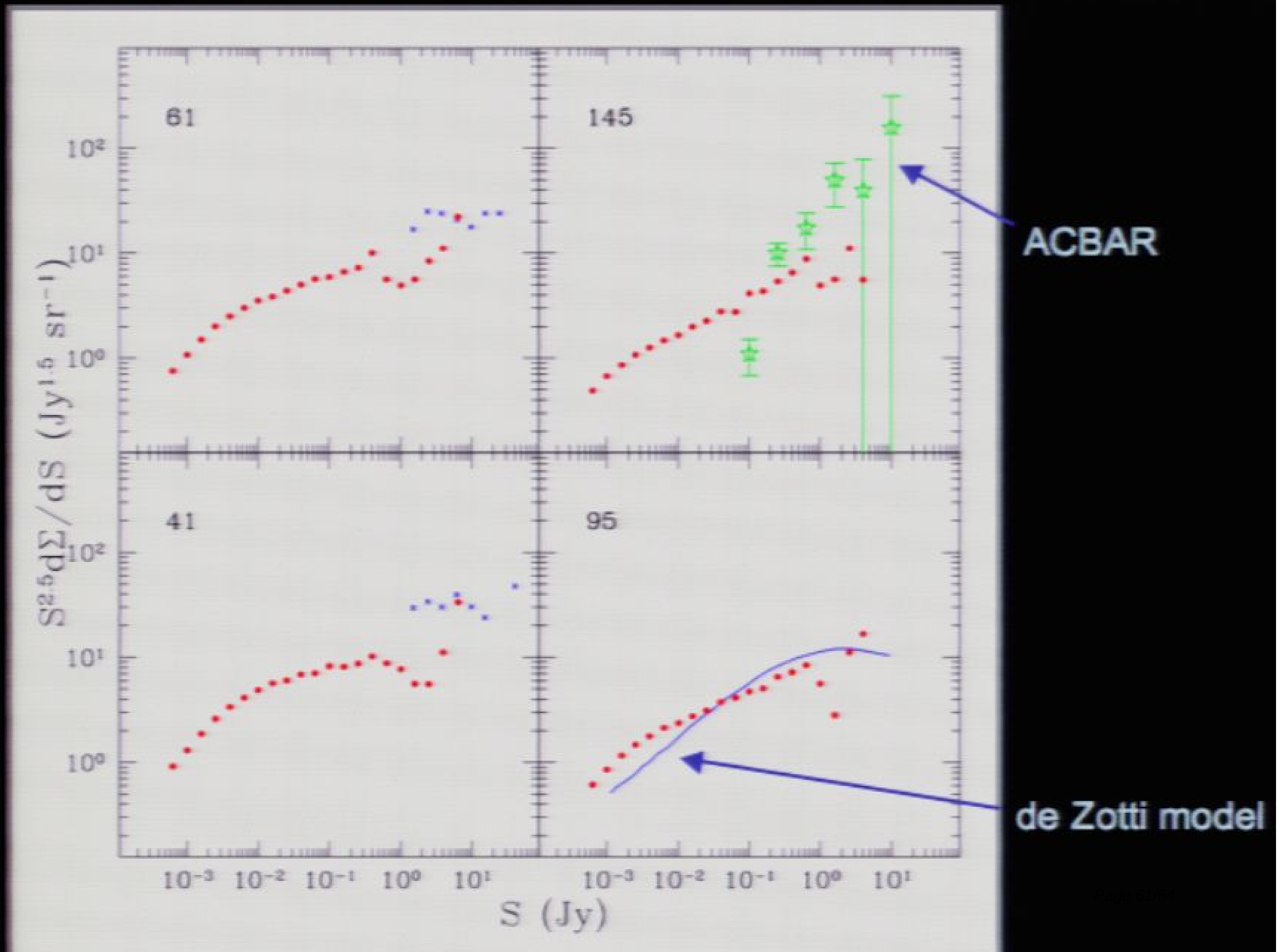

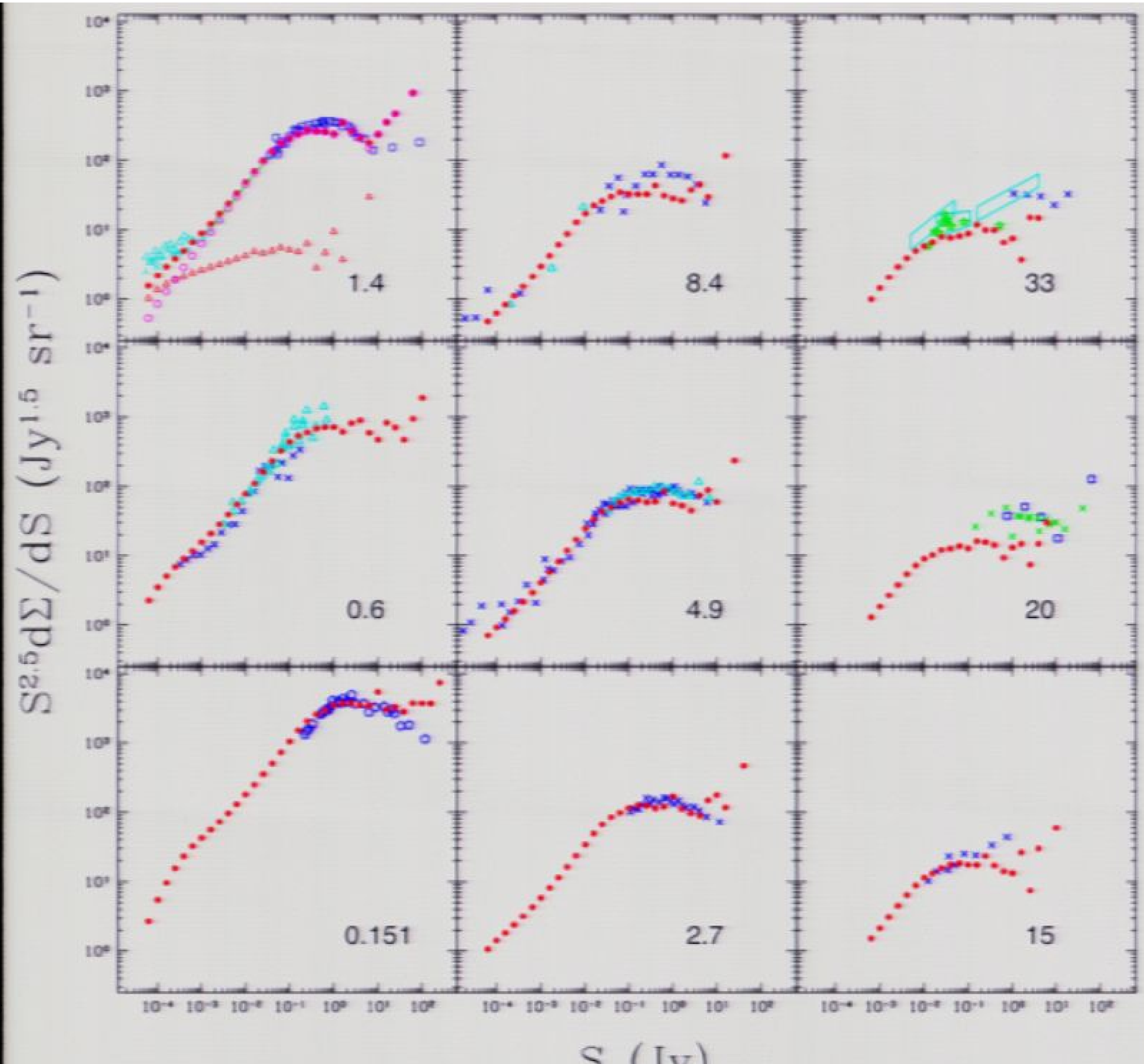

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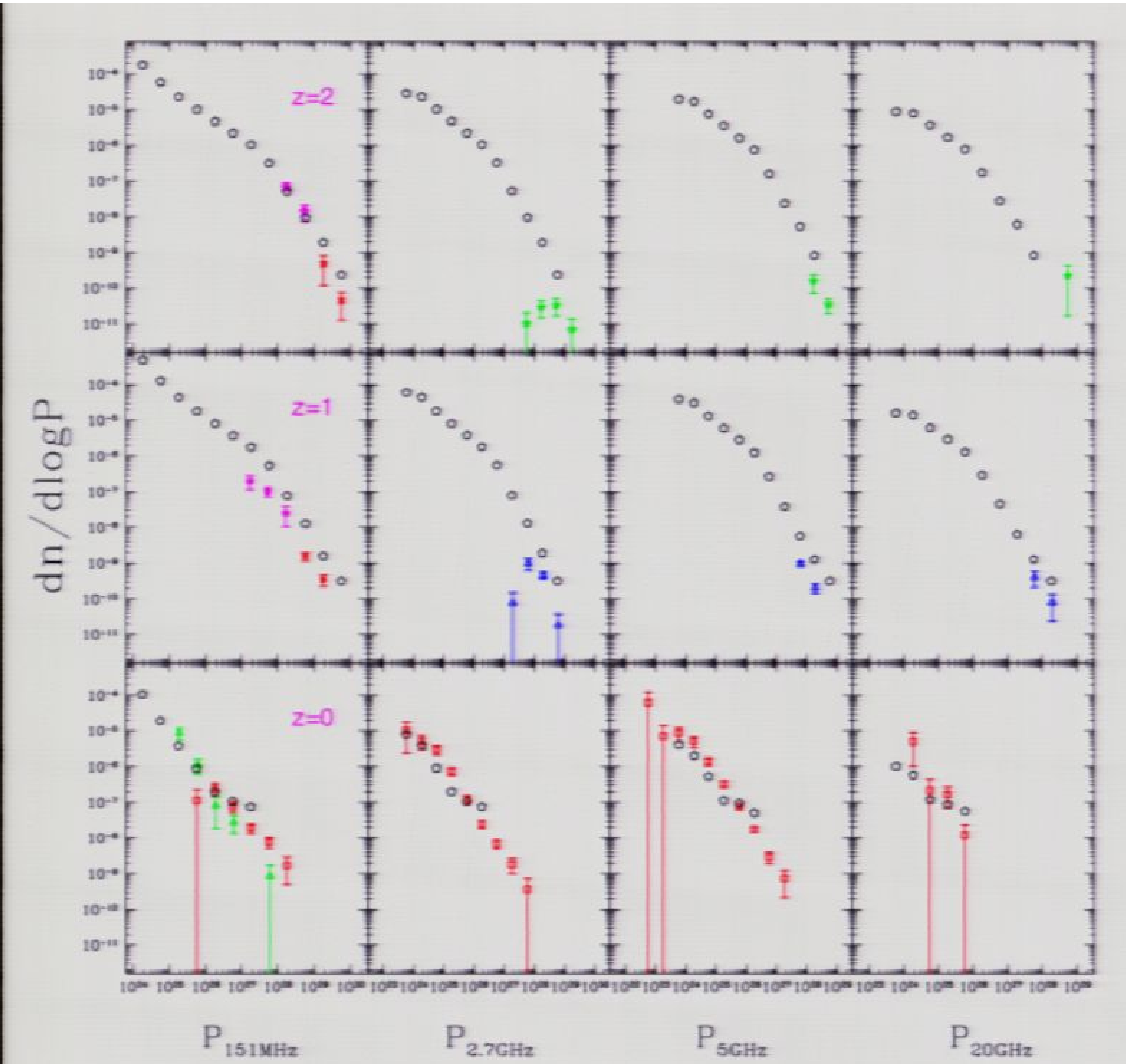
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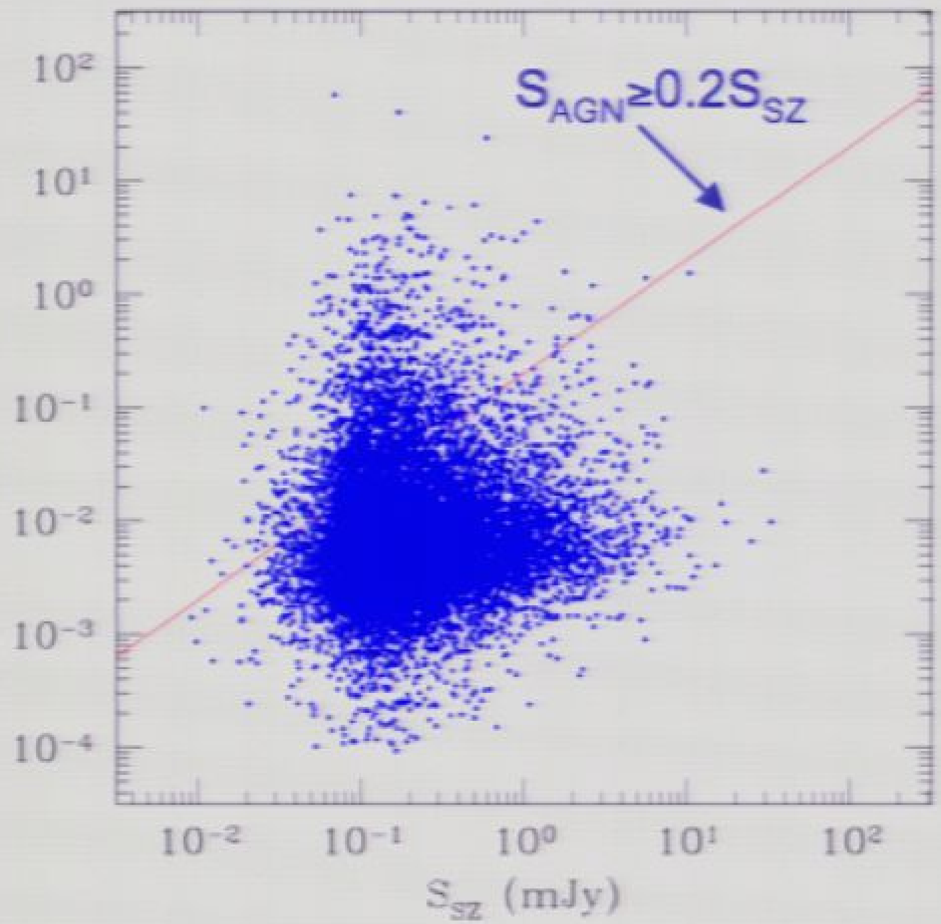

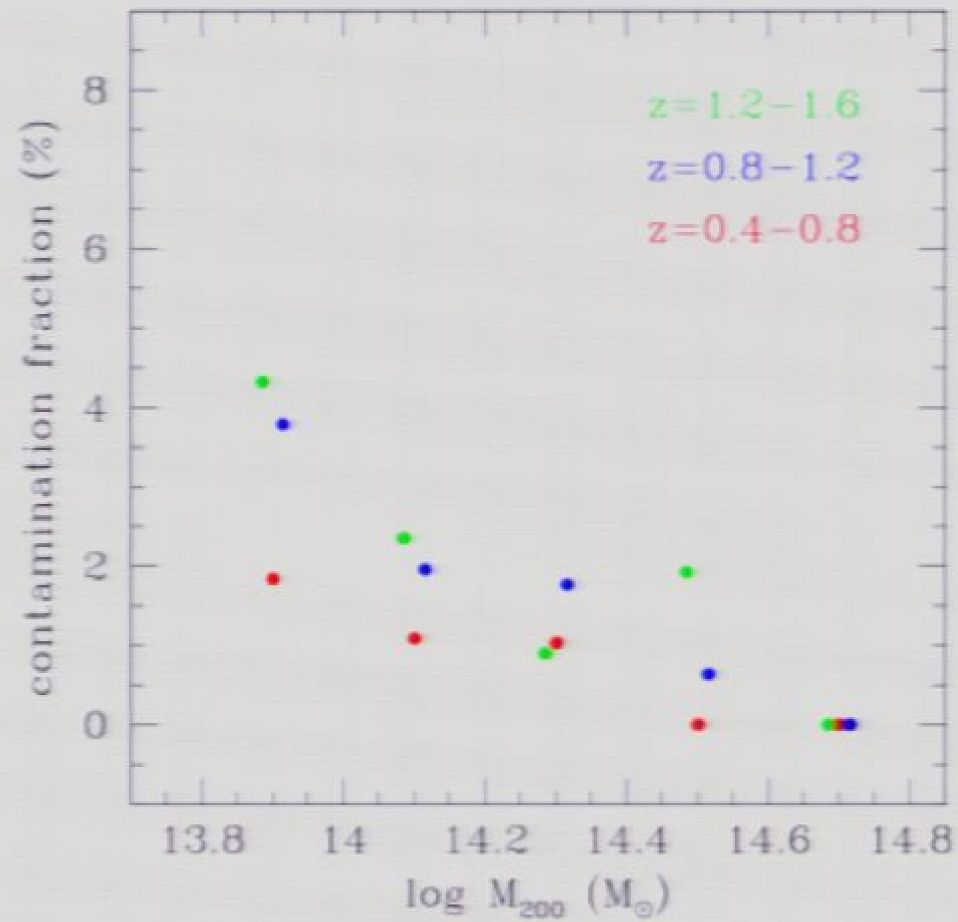

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