Title: Radio point sources and SZE surveys

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Abstract:

Radio sources and SZE surveys

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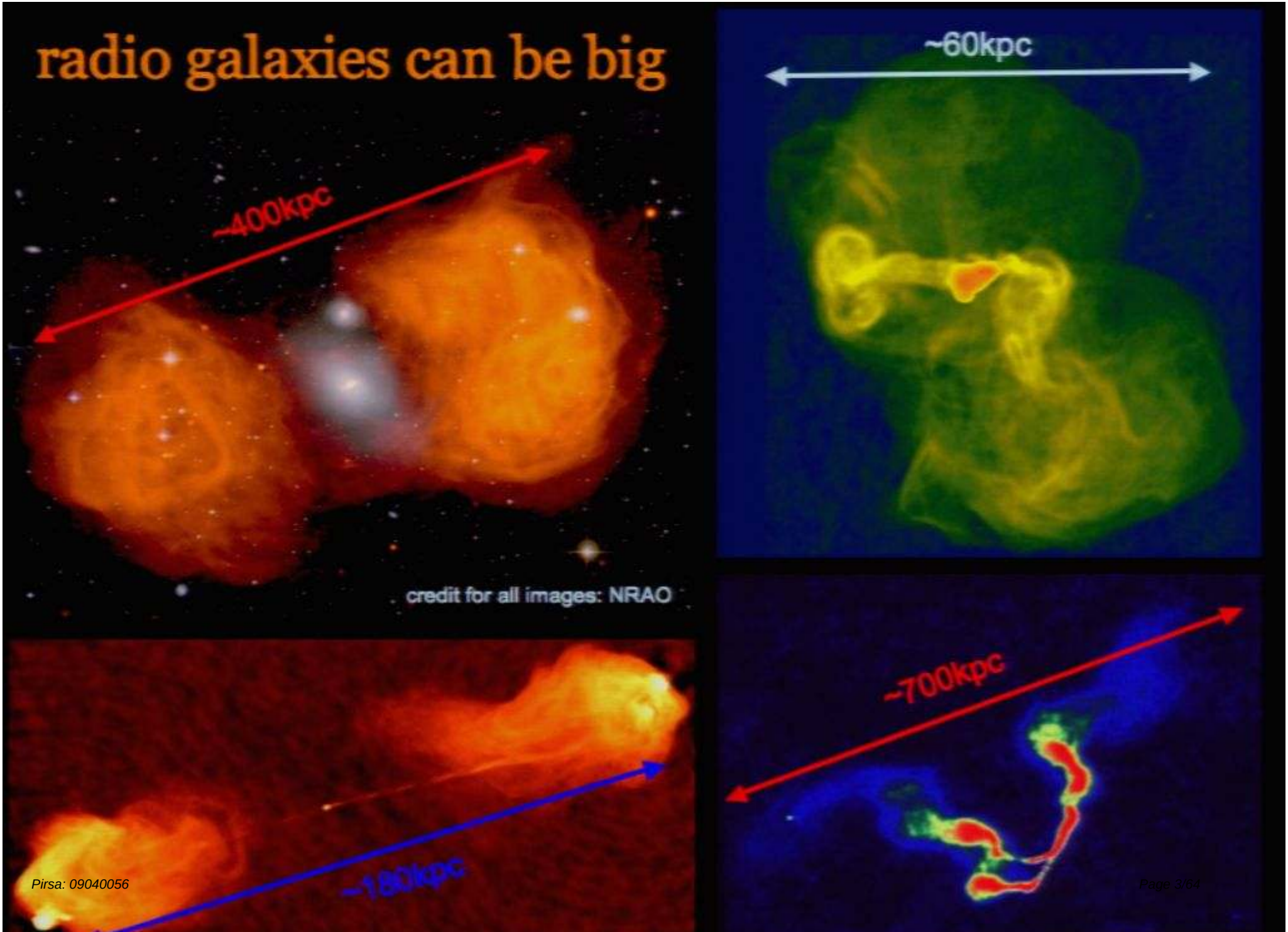
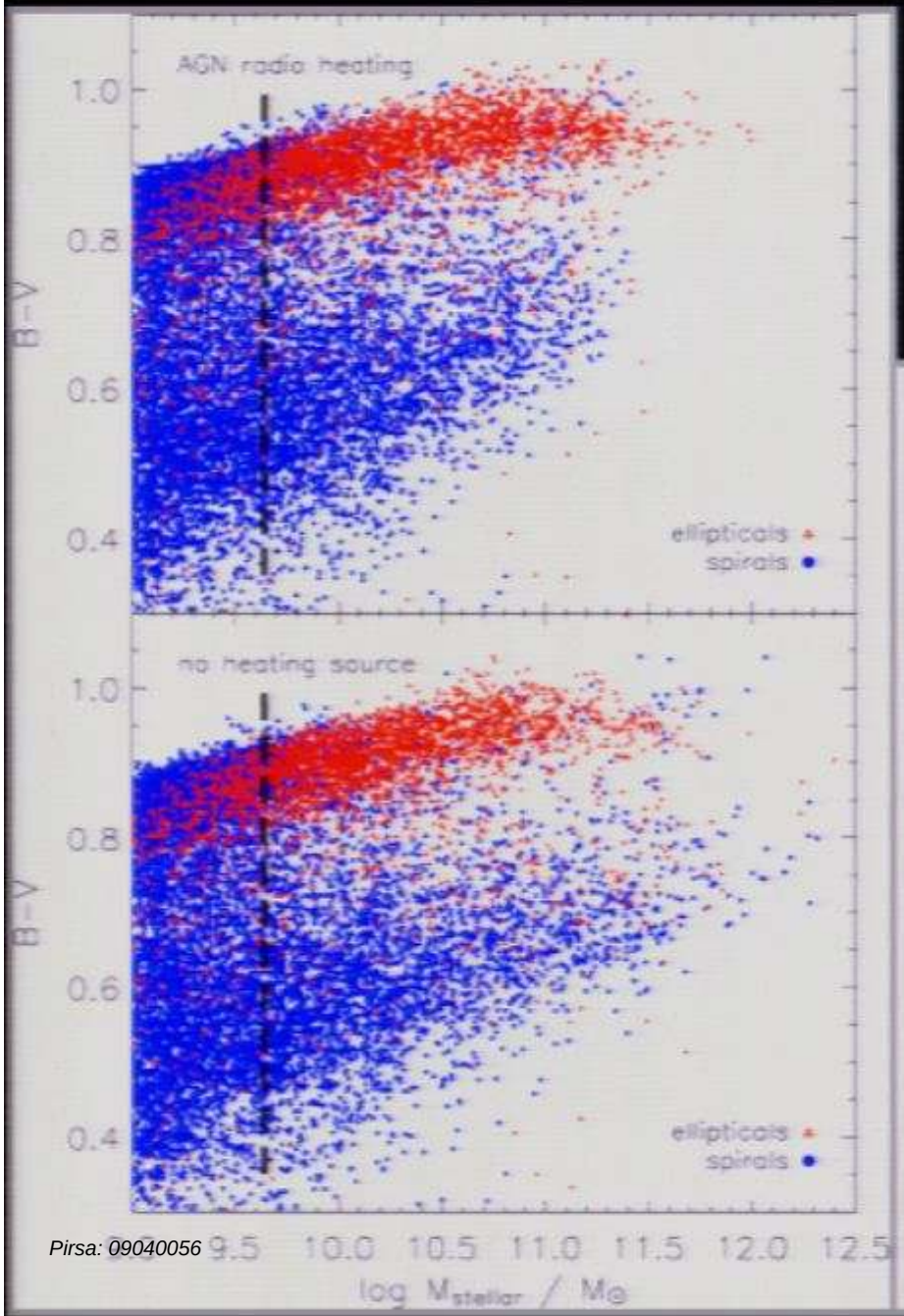
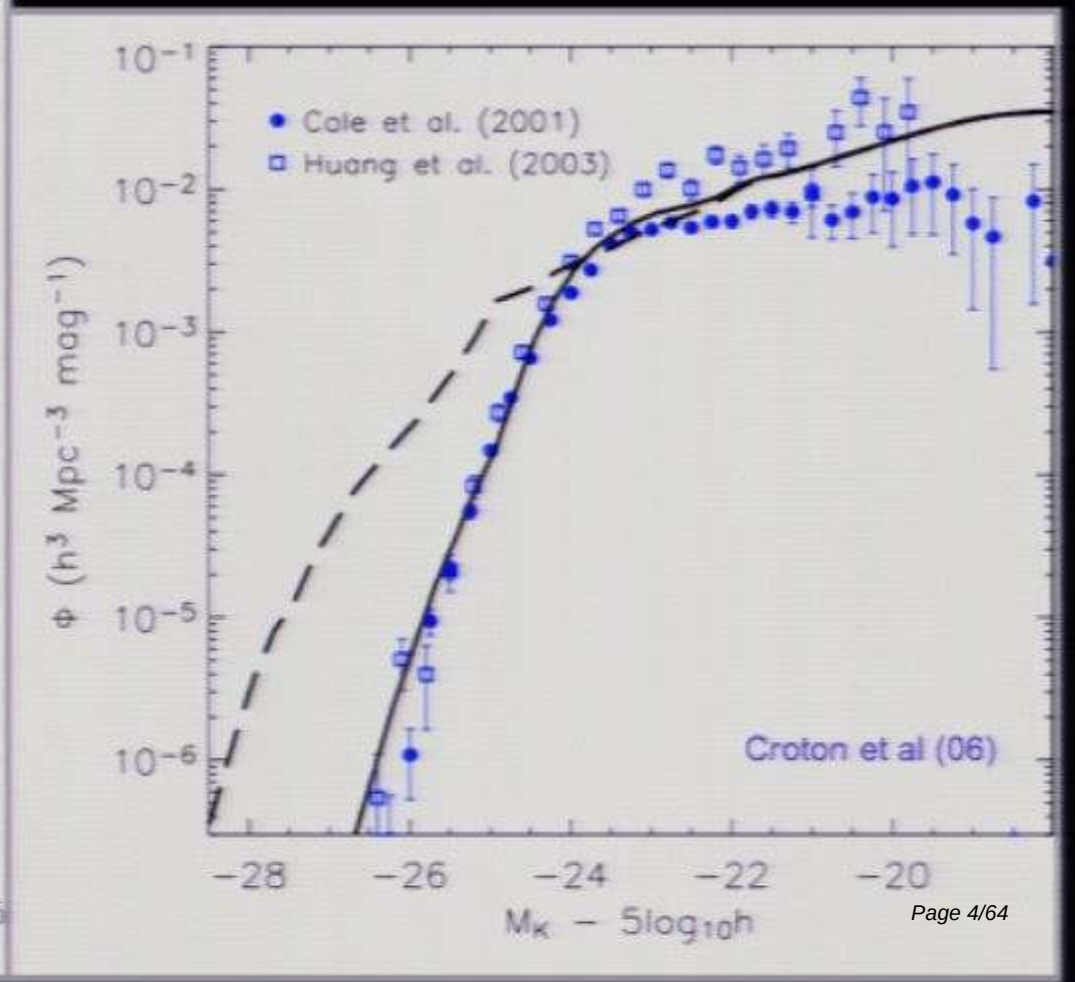
Kevin Huffenberger, Neelima Sehgal, Hy Trac, Paul Bode,
Carlos Hernandez-Monteagudo, Sudeep Das


radio galaxies can be big
~400kpc
~60kpc
credit for all images: NRAO
~700kpc
~180kpc

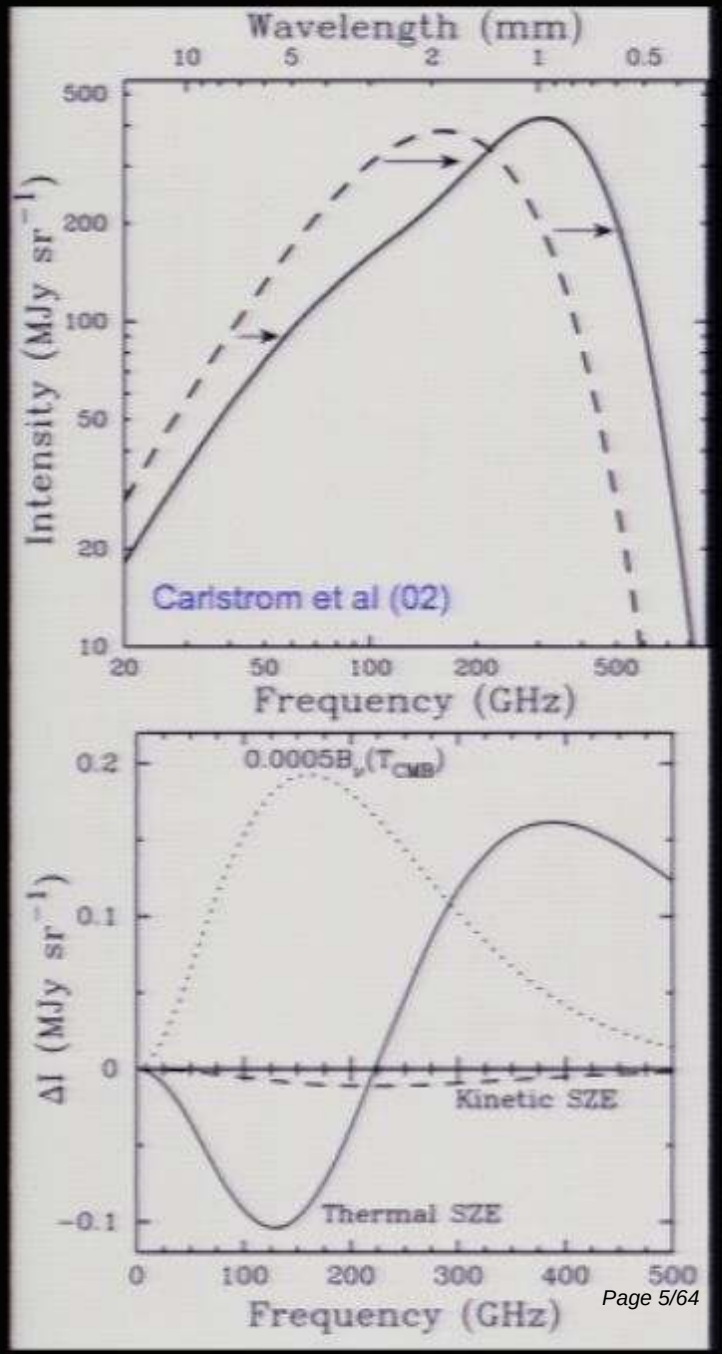
motivation: to make the bright end of the LF and CMD right





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



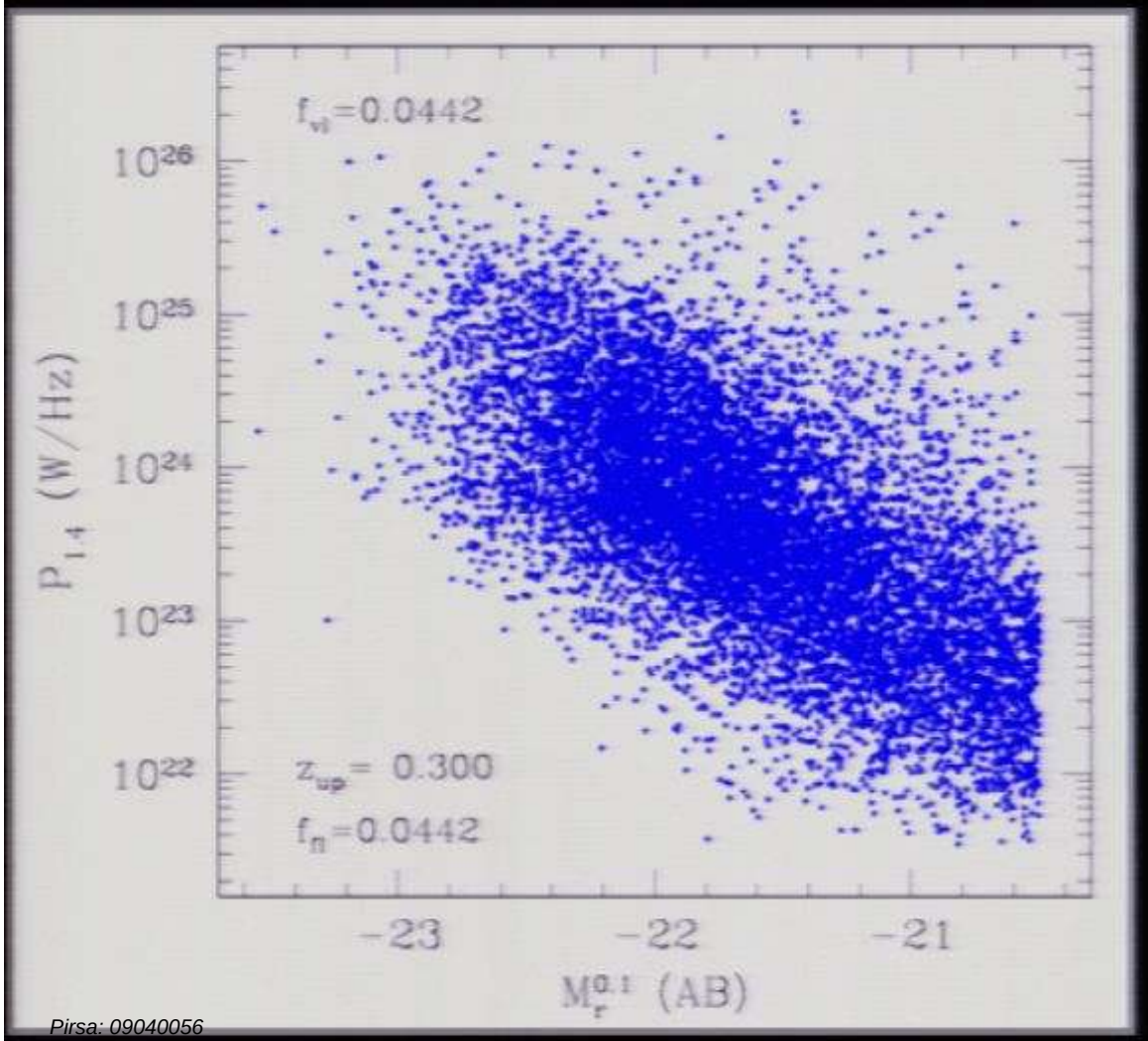
outline

- 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≤0.3

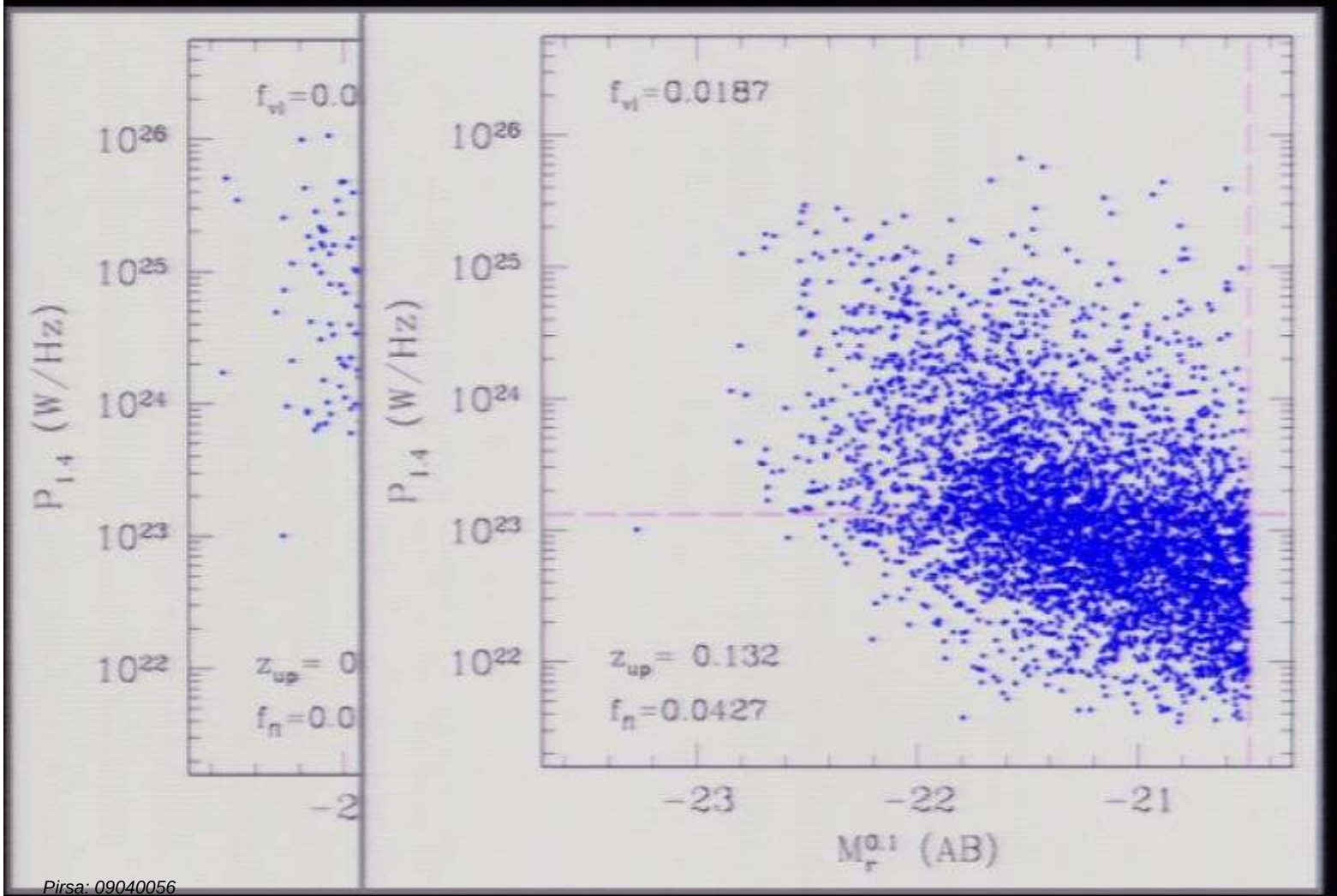
- using SDSS DR6 main galaxy sample as parent sample, containing ~220,000 galaxies down to $M_r \leq -20.5$ (about M_*)
- cross-matched with NVSS and FIRST surveys at 1.4 GHz to generate the largest radio galaxy catalog at z≤0.3 to date: 10,500 RGs stronger than 3 mJy
- improvements over previous studies
  - 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



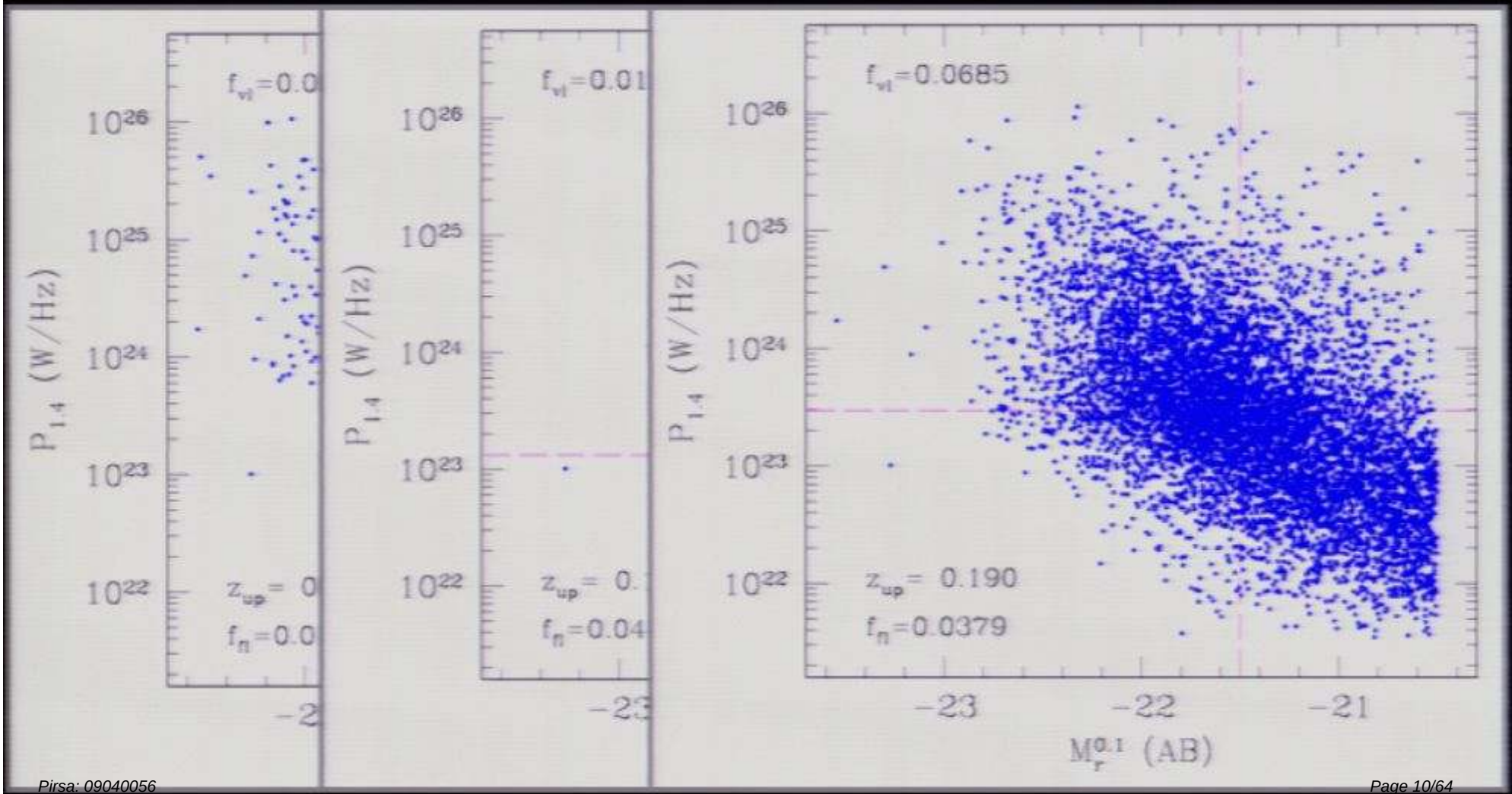
whole sample

bivariate luminosity function



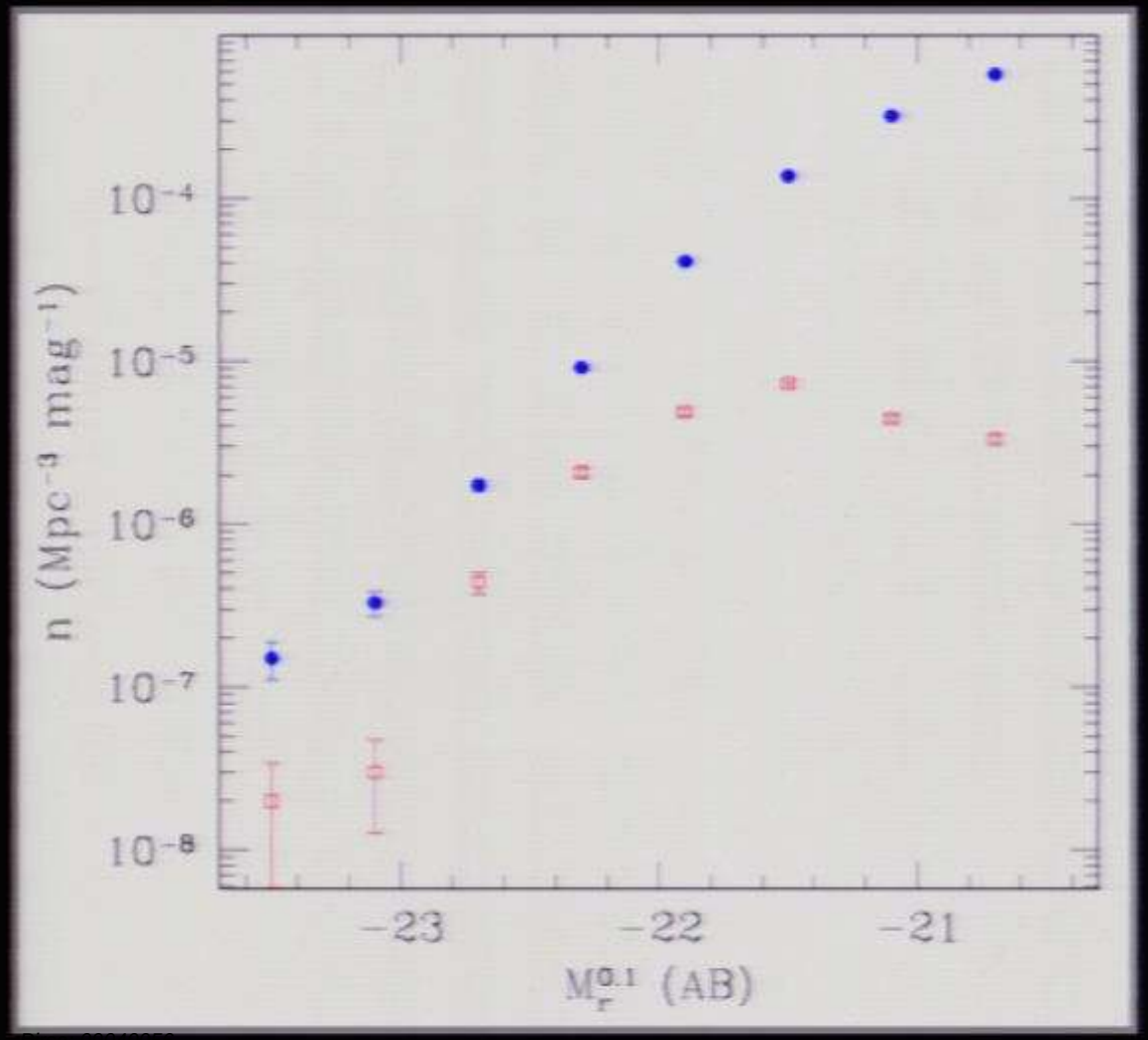
whole sample M≤−20.5 volume-limited

bivariate luminosity function



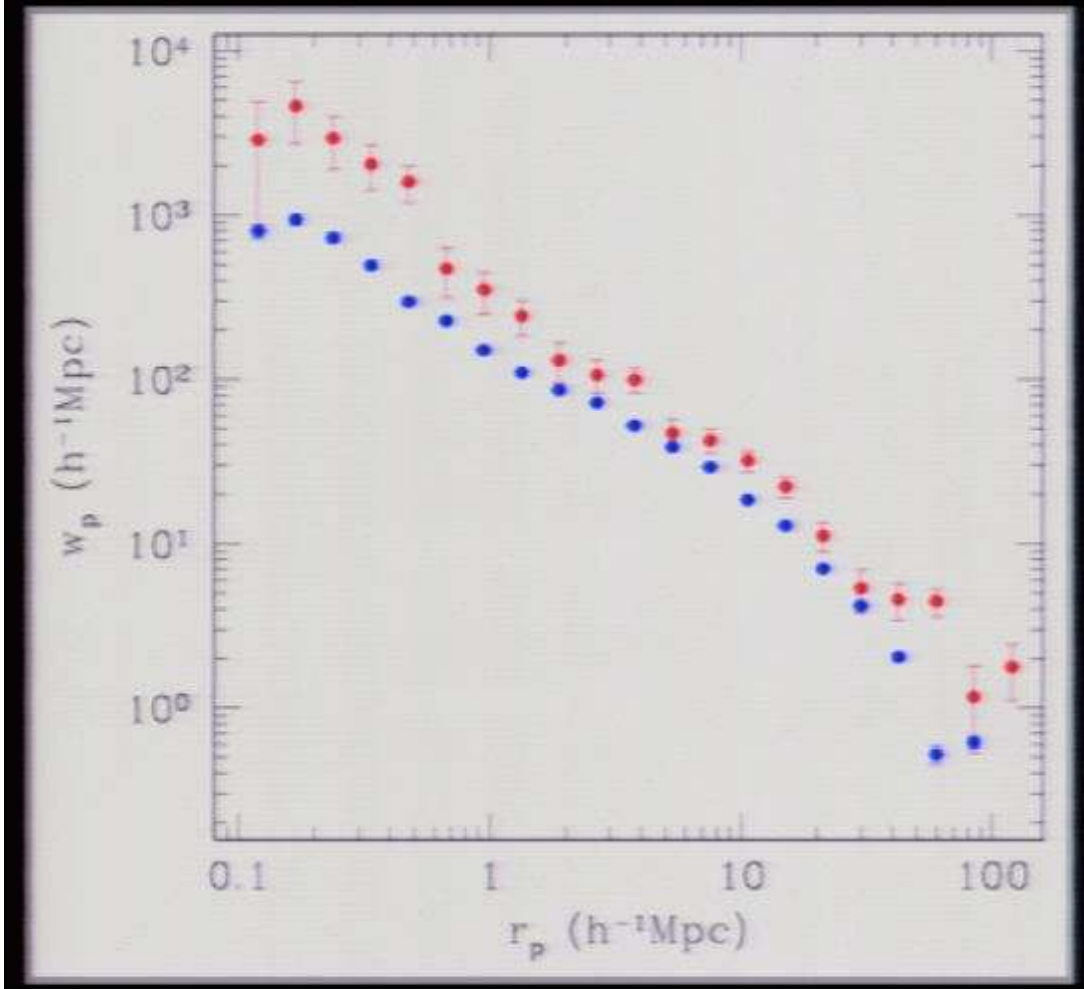
whole sample M≤−20.5 volume-limited M≤−21.5 volume-limited

optical luminosity function



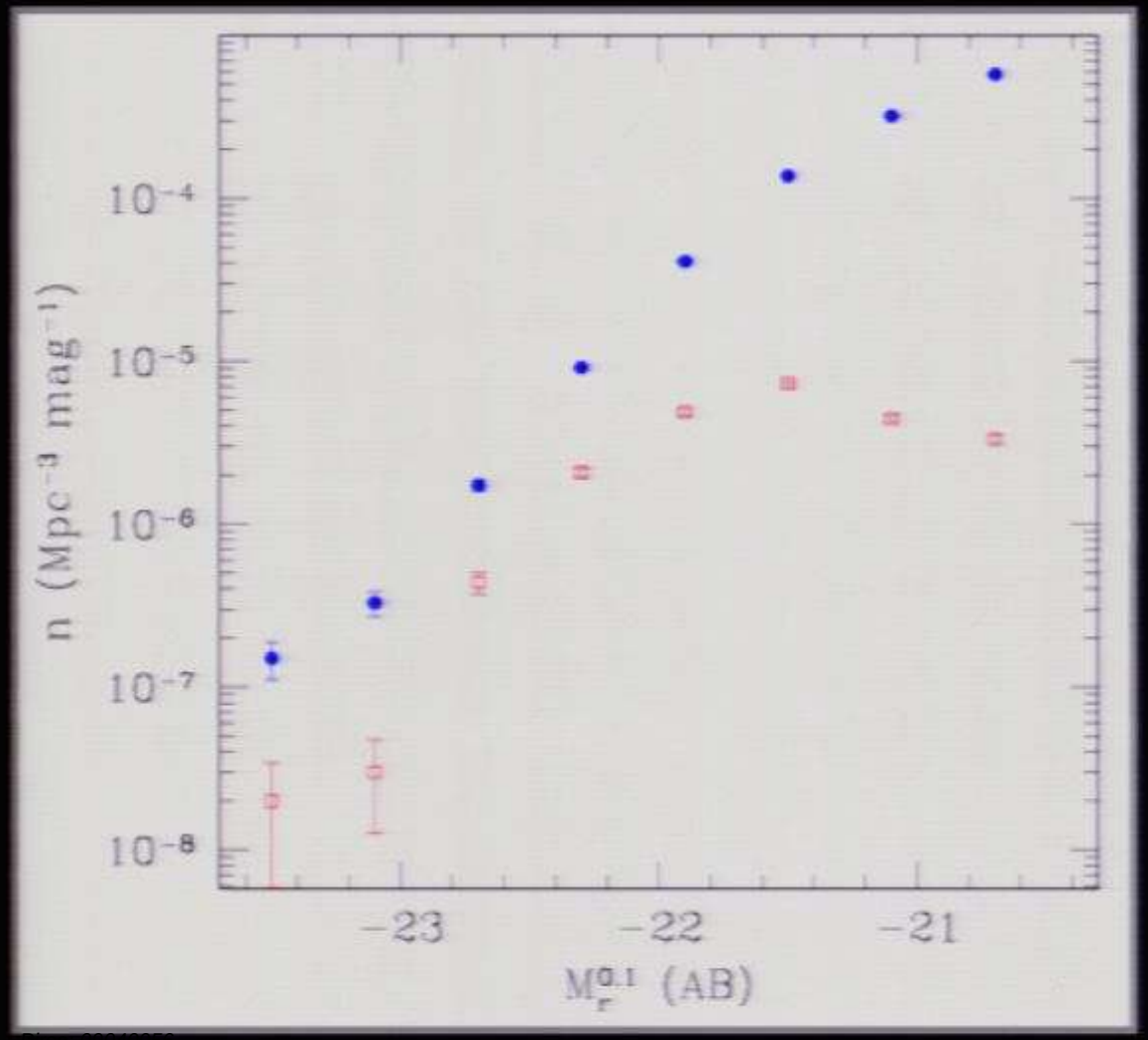
- 0.02≤z≤0.132
- 108,873 galaxies
- 2,253 RGs
- 2.1% of galaxies more luminous than M. have radio power logP≥23.12
- fiber collision correction applied

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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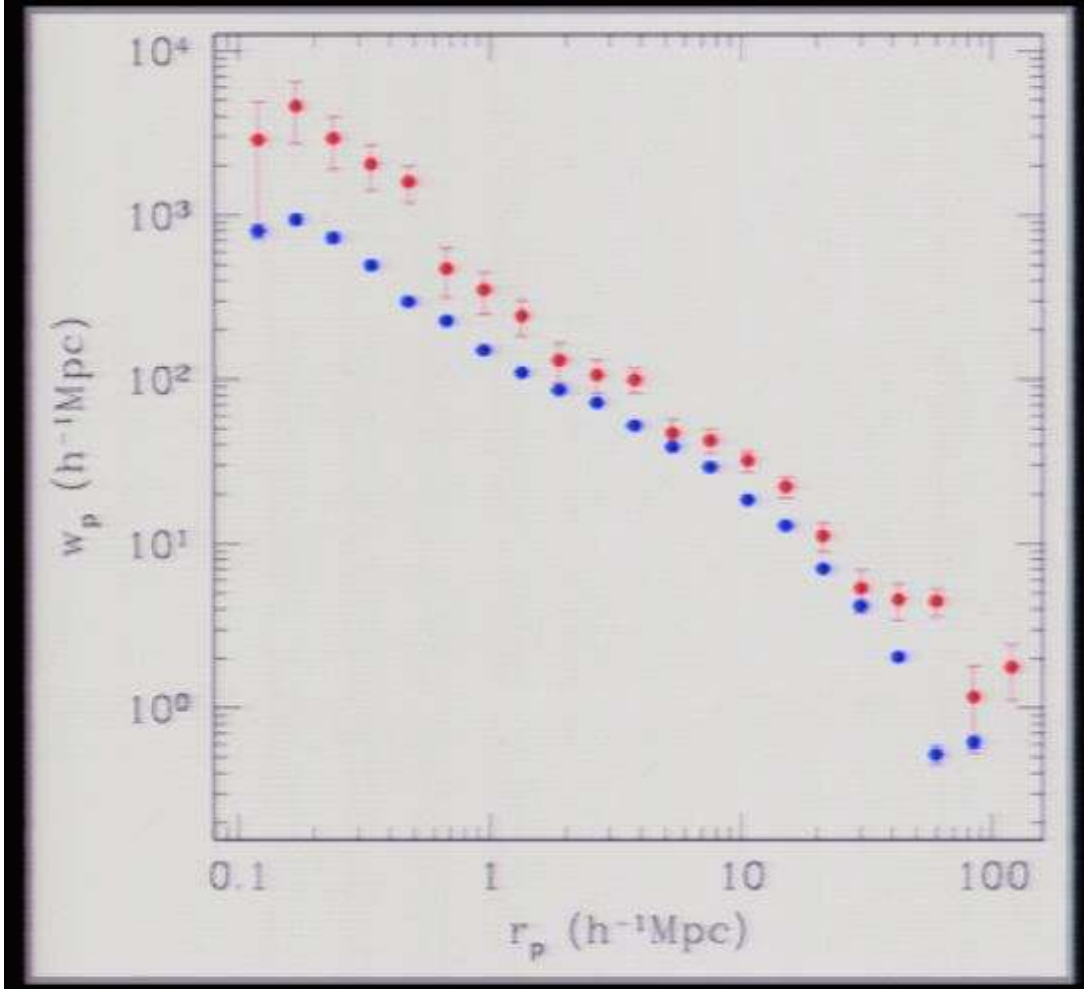

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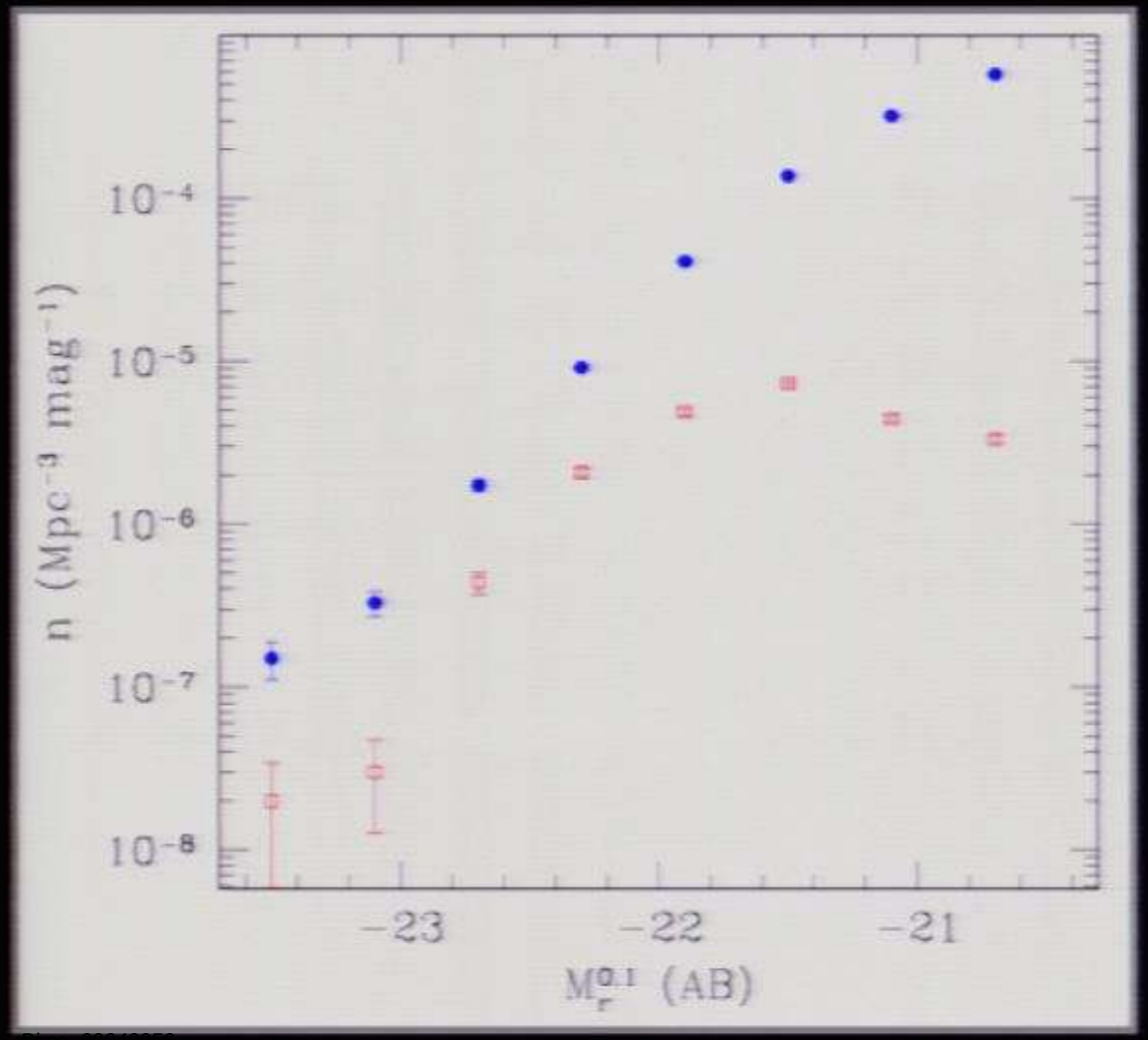

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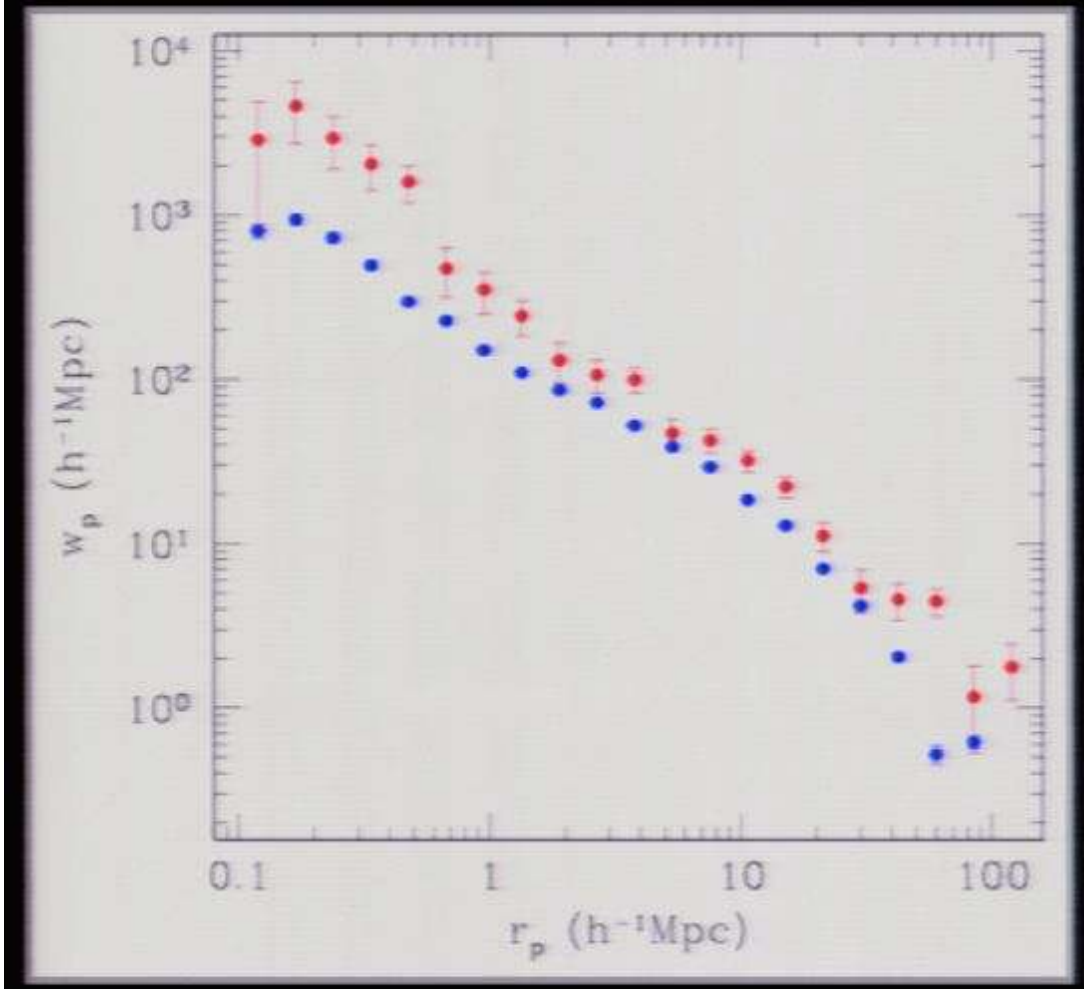

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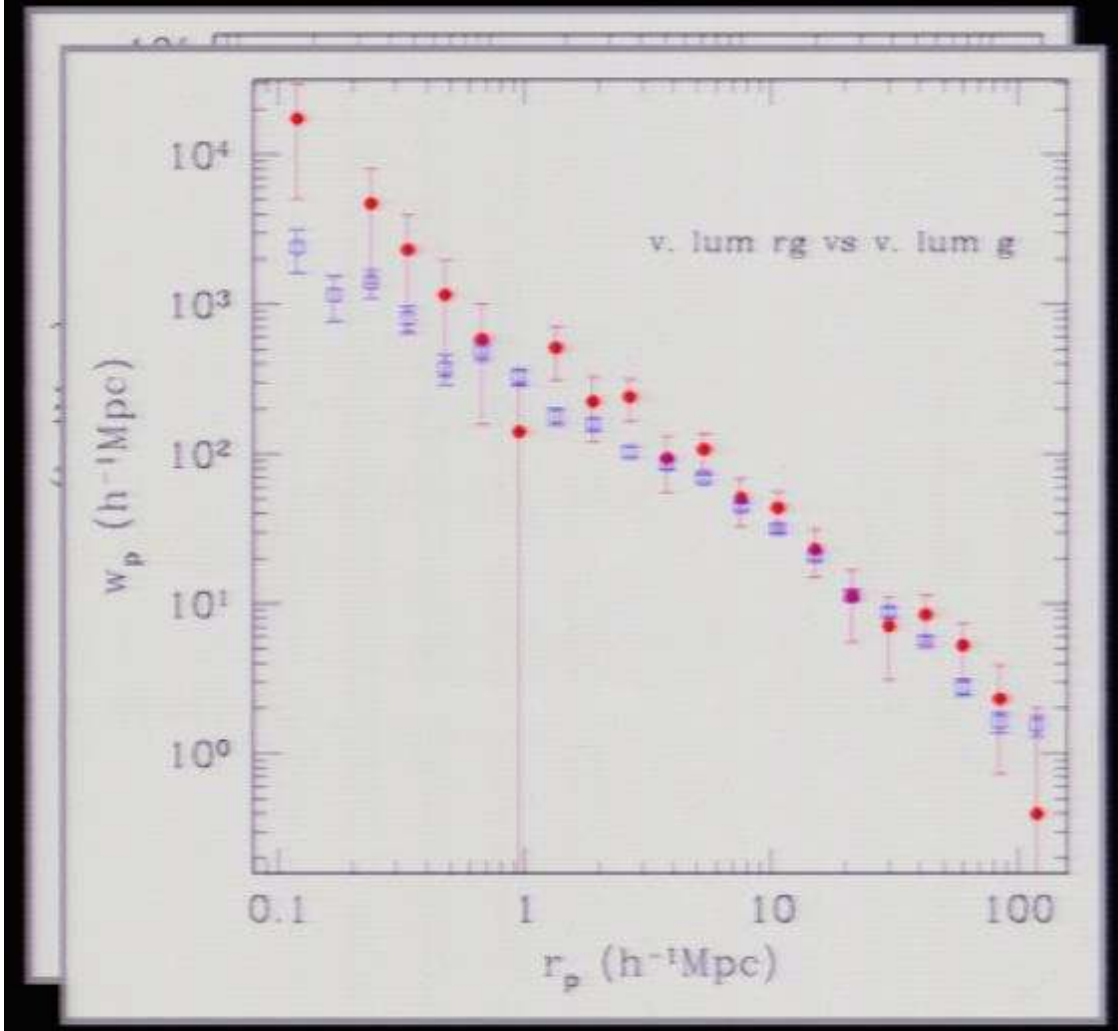

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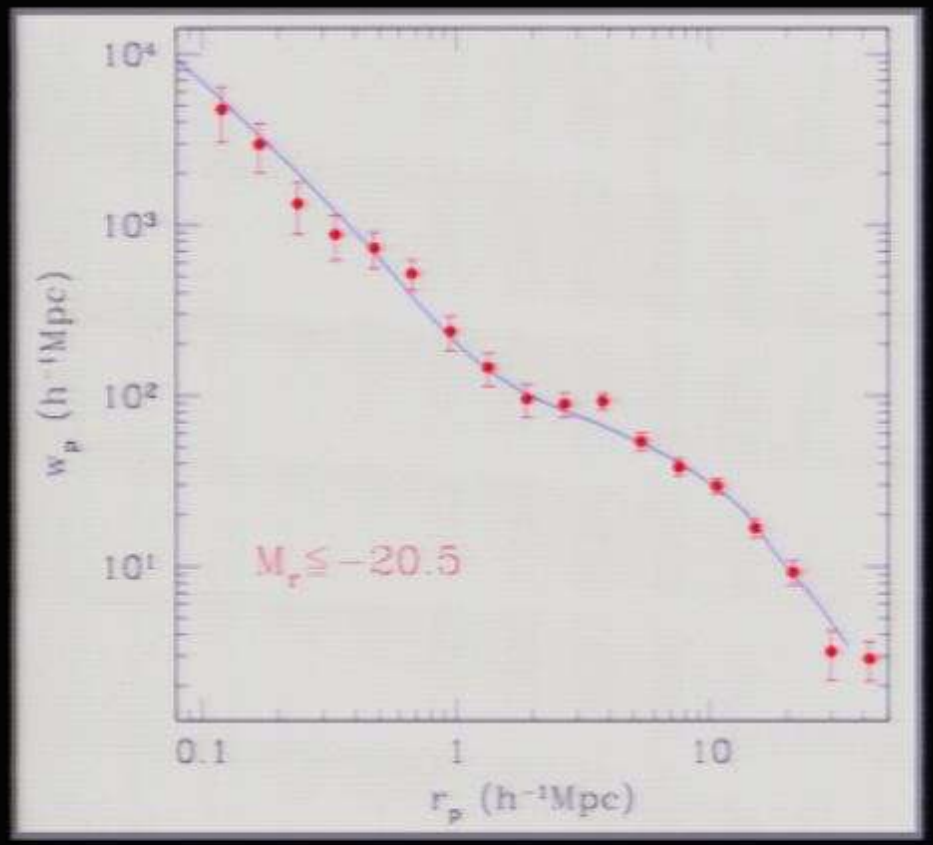
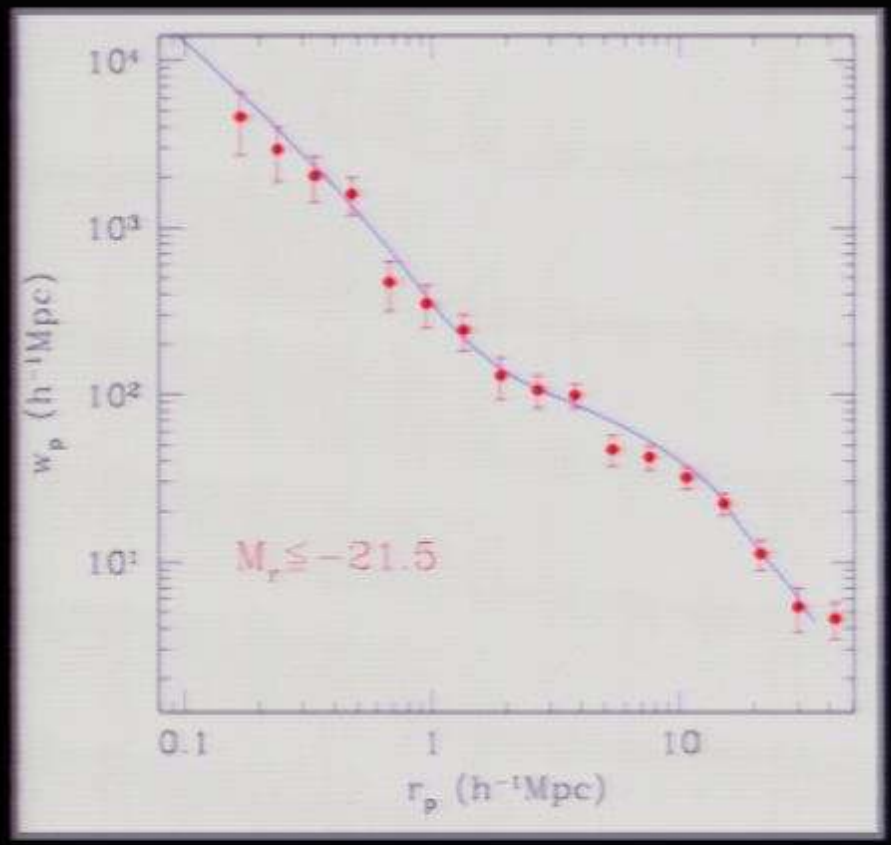
correlation function: HOD modeling





- 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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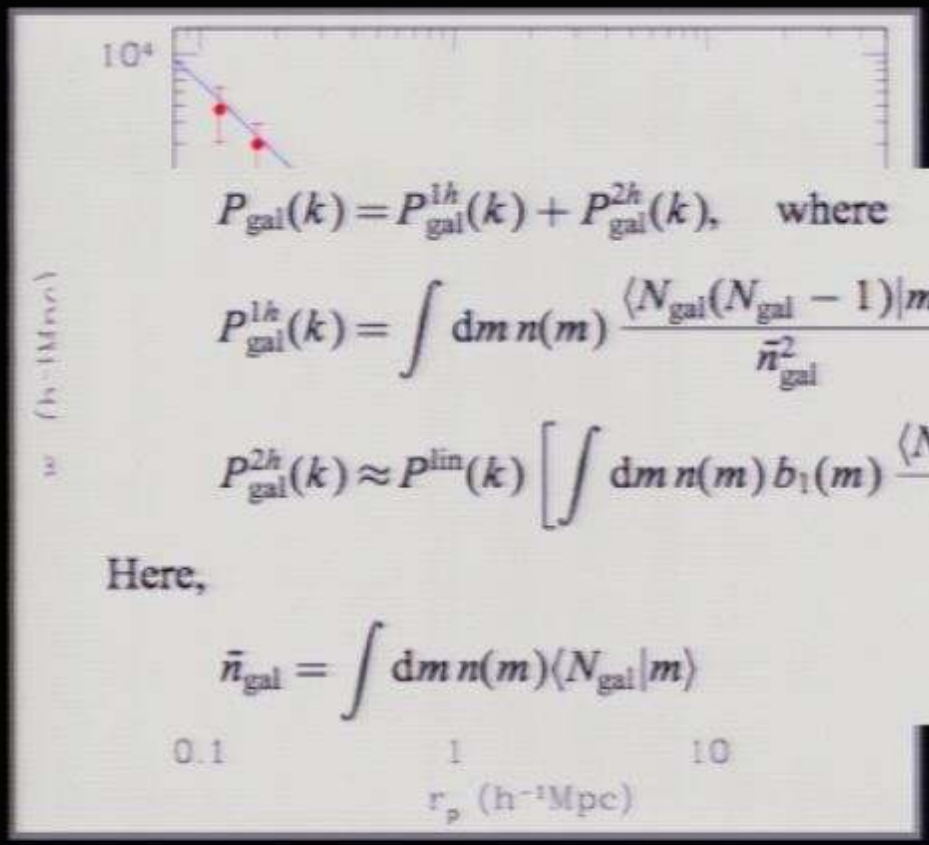


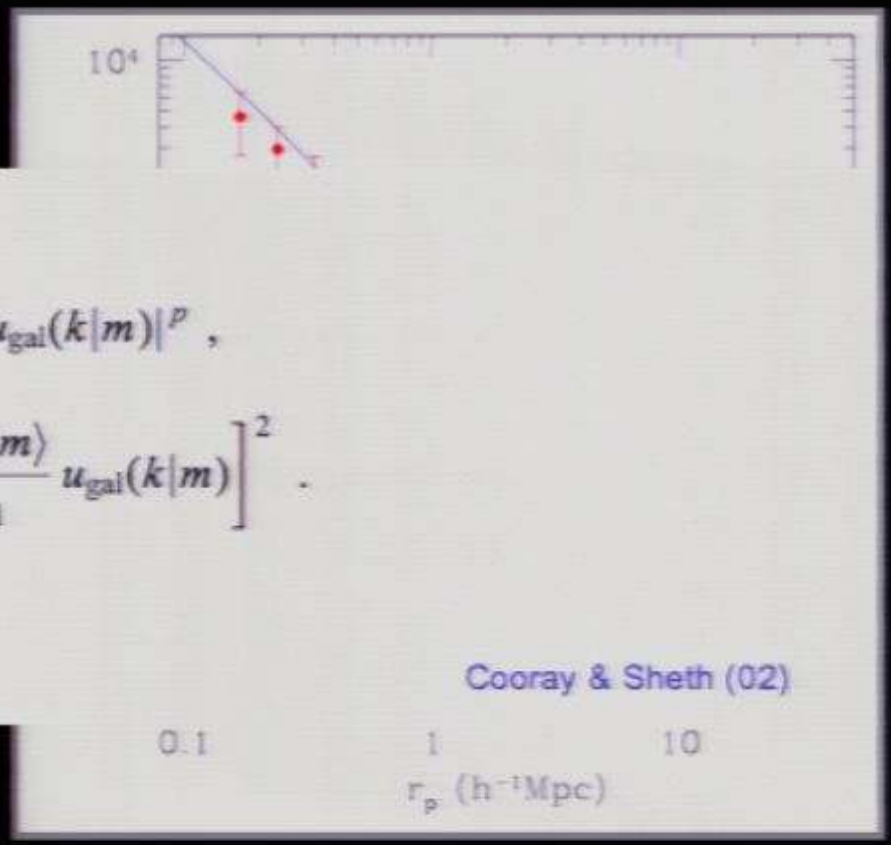
$$P_{\rm gal}(k) = P^{1h}_{\rm gal}(k) + P^{2h}_{\rm gal}(k), \quad \text{where}$$

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

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

Here,

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



Cooray & Sheth (02)

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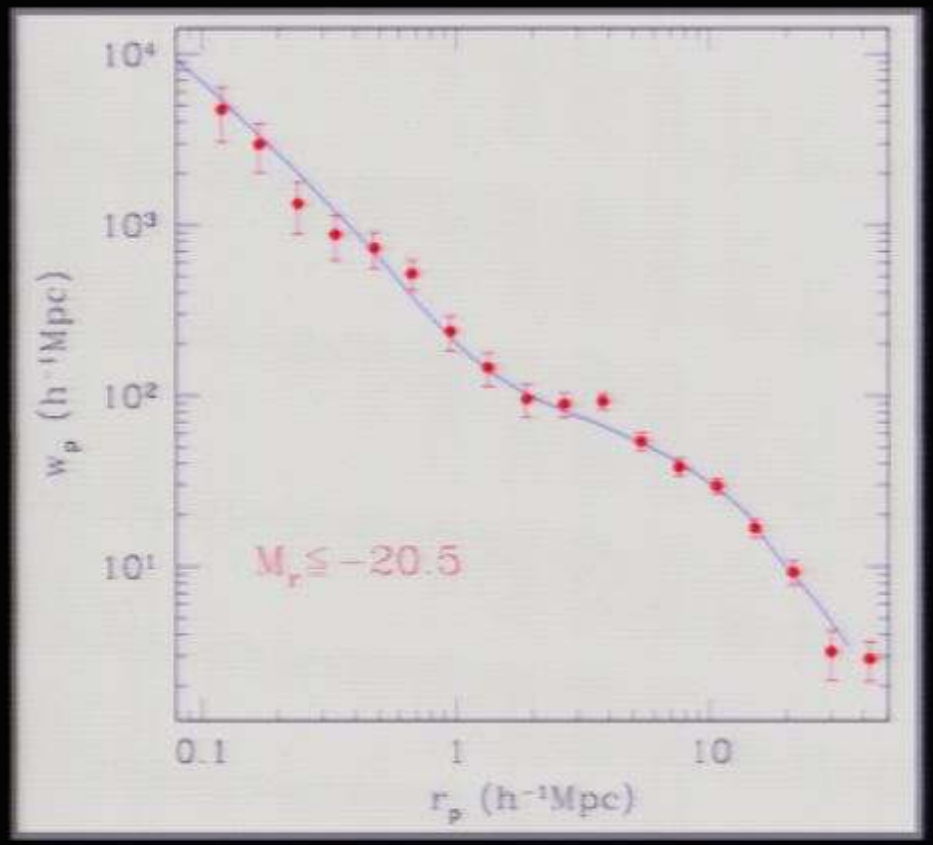

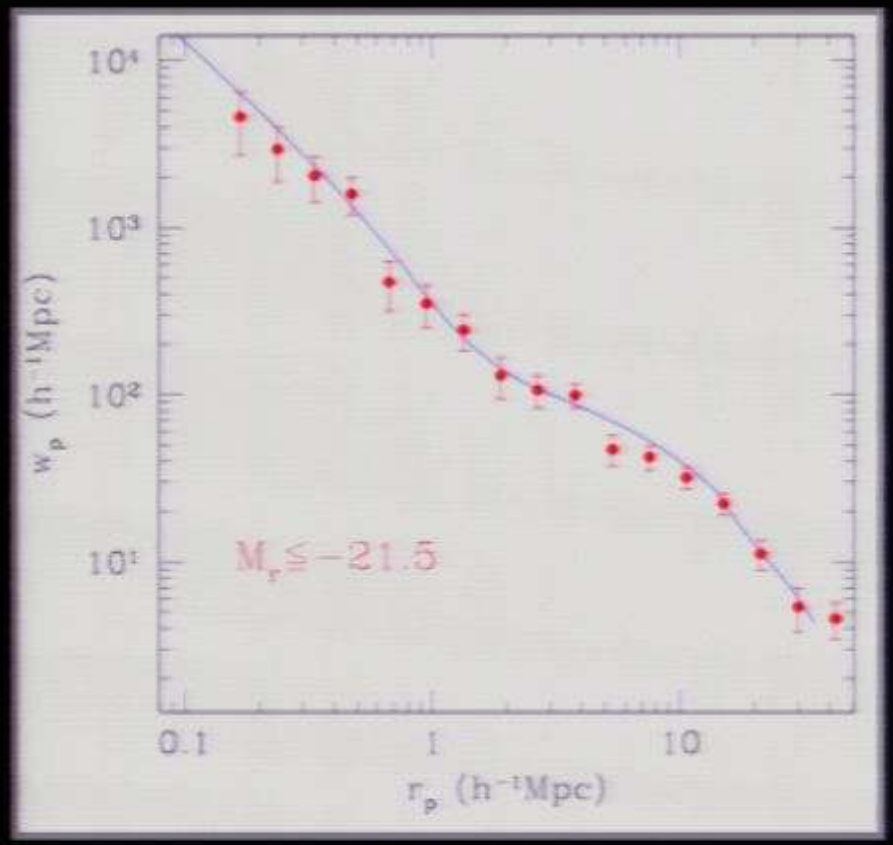

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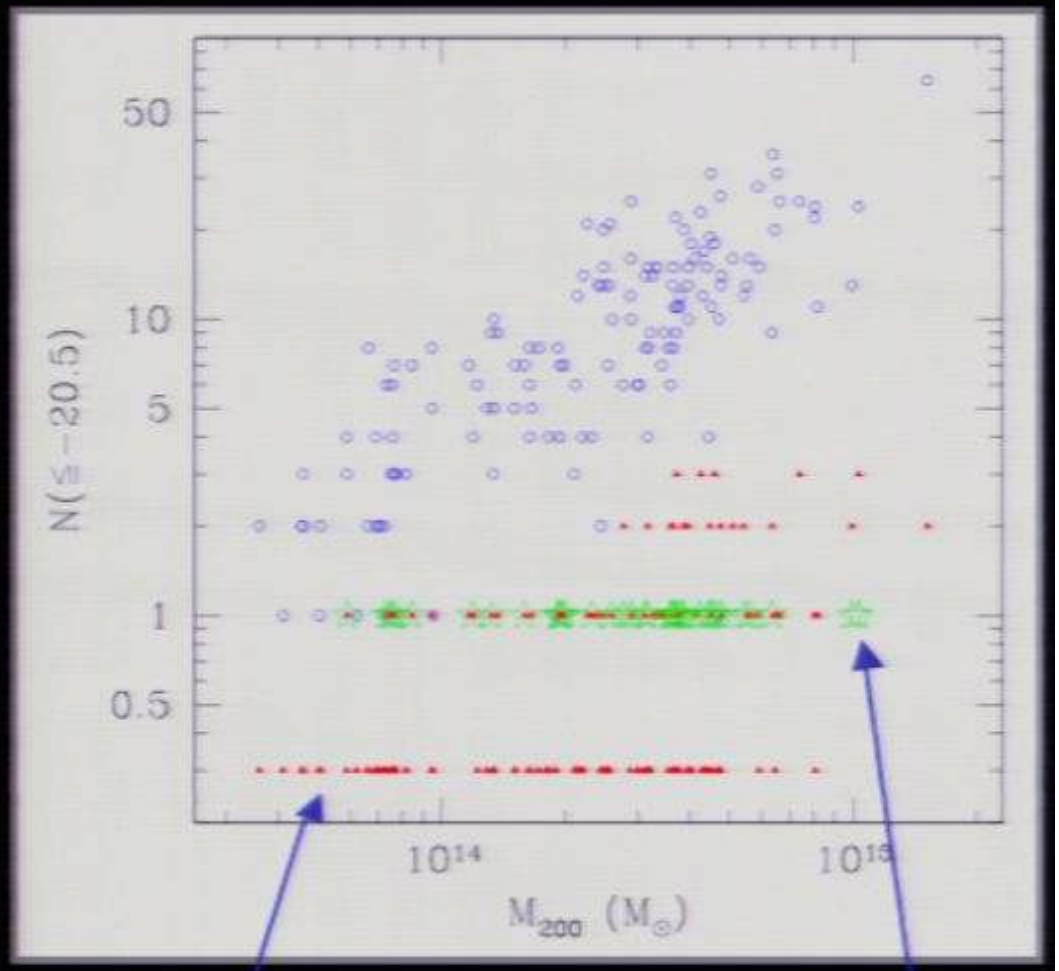
RGs in massive halos: halo occupation number

- 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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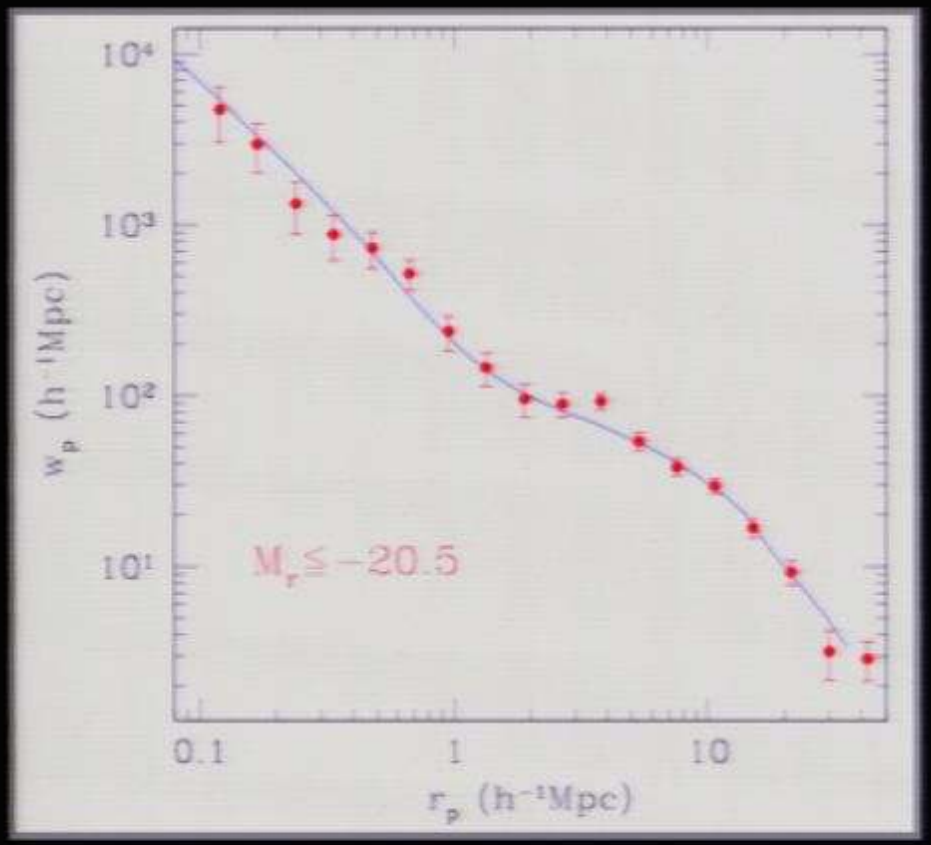

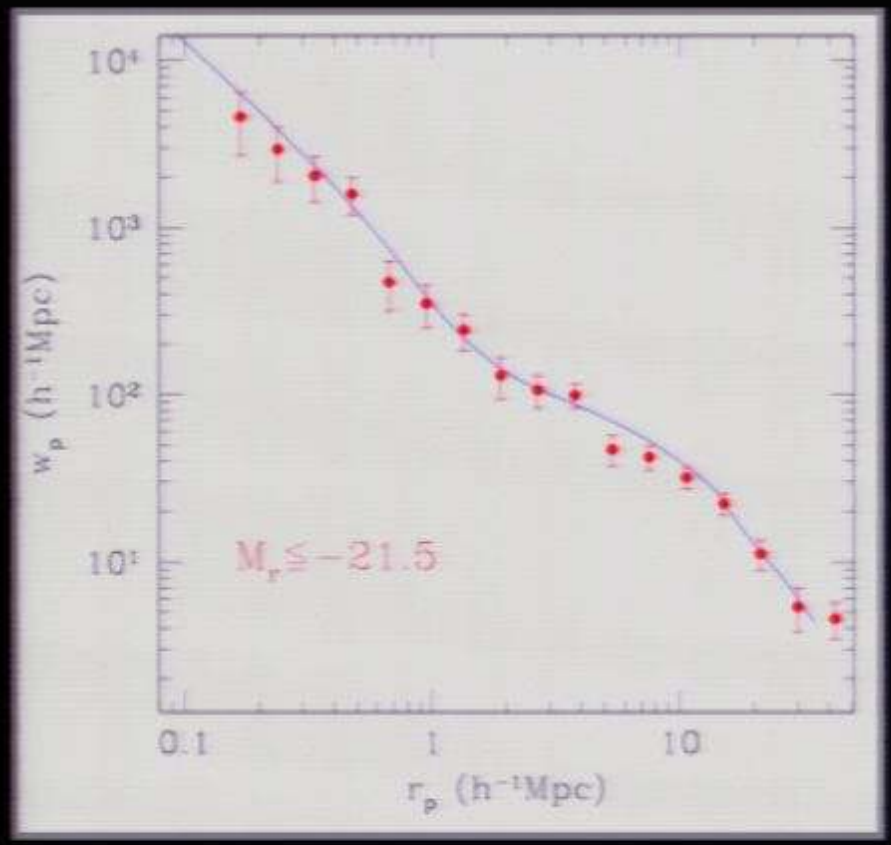

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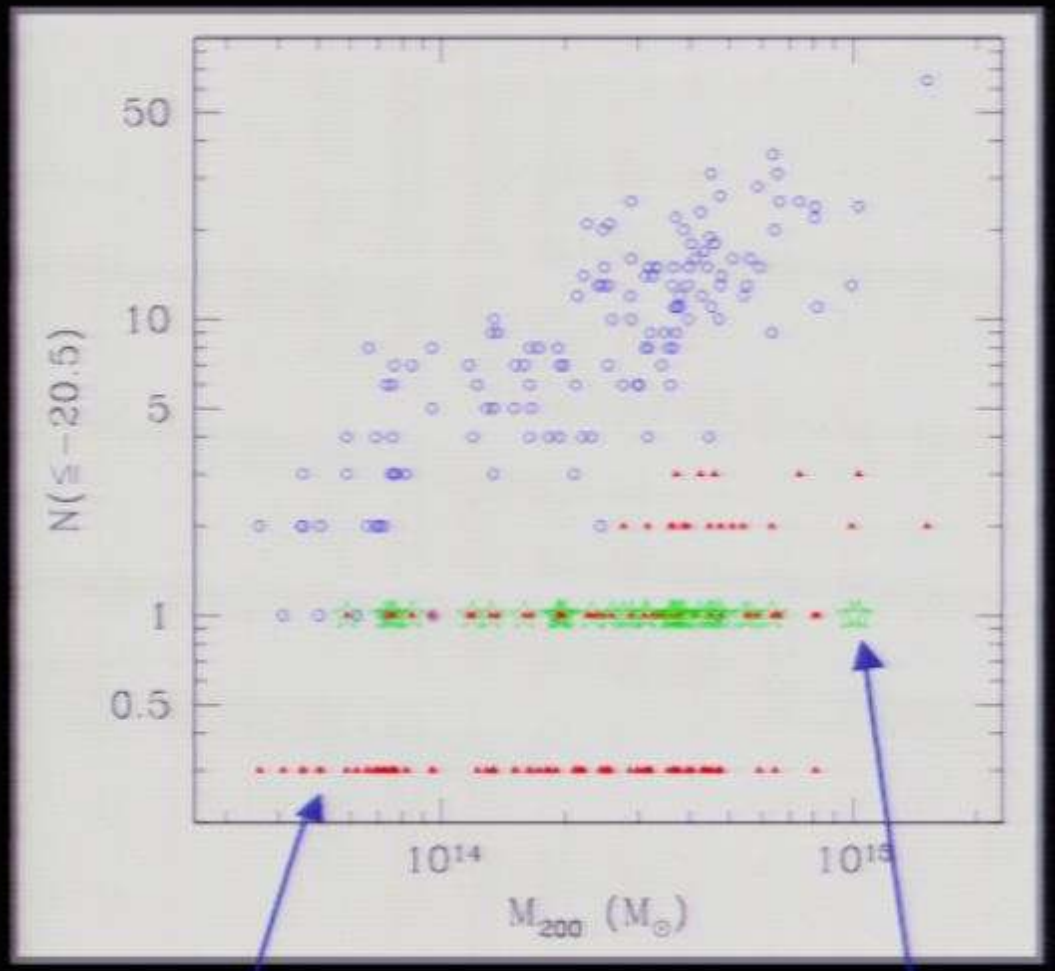
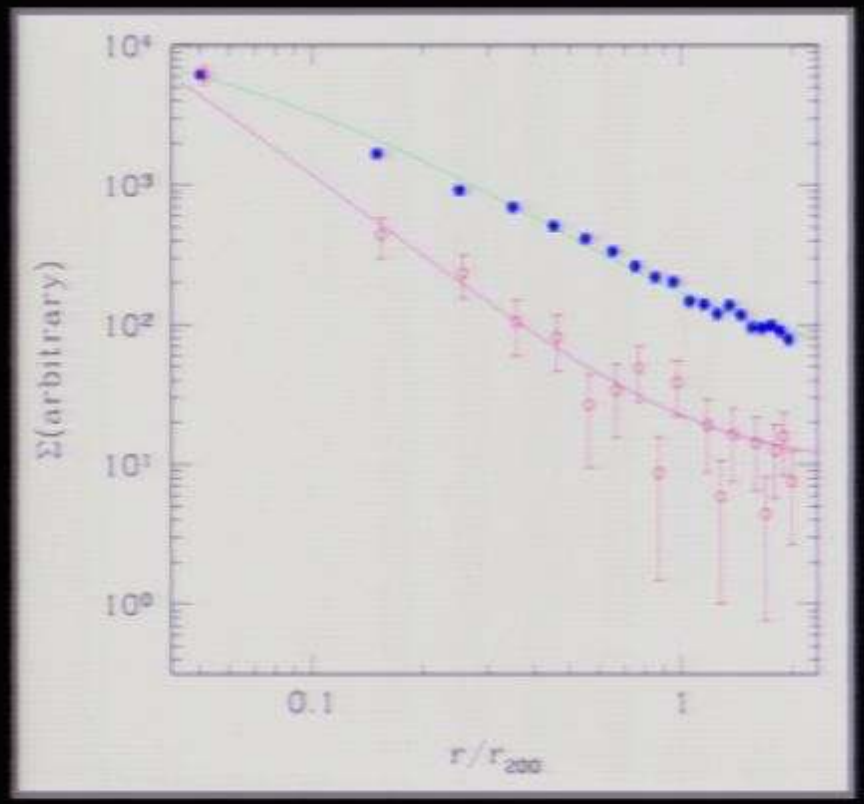
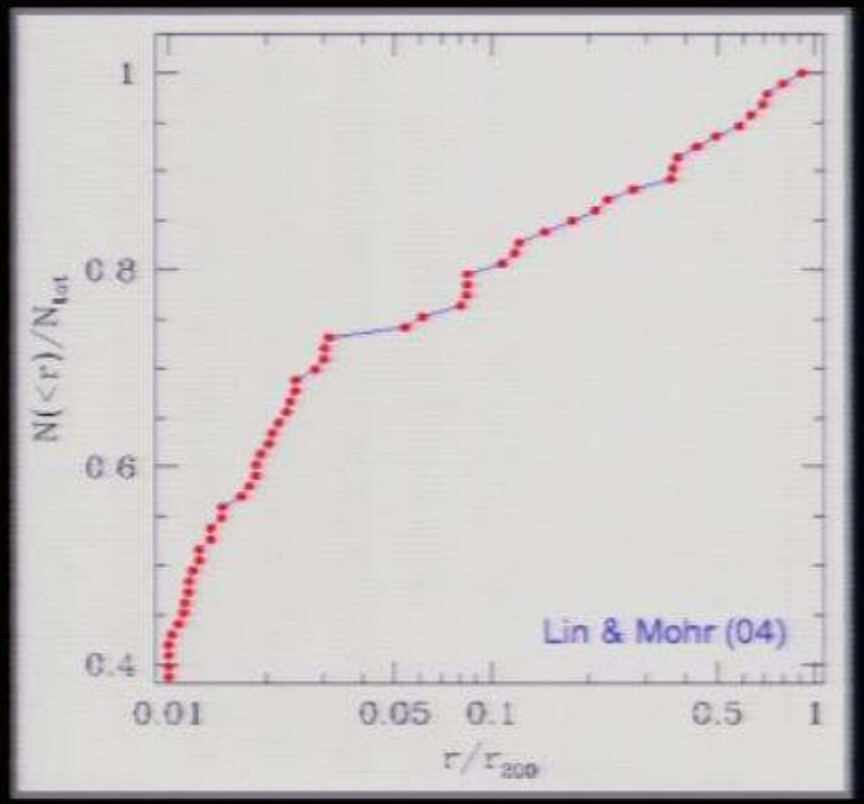


RGs in massive halos: spatial distribution

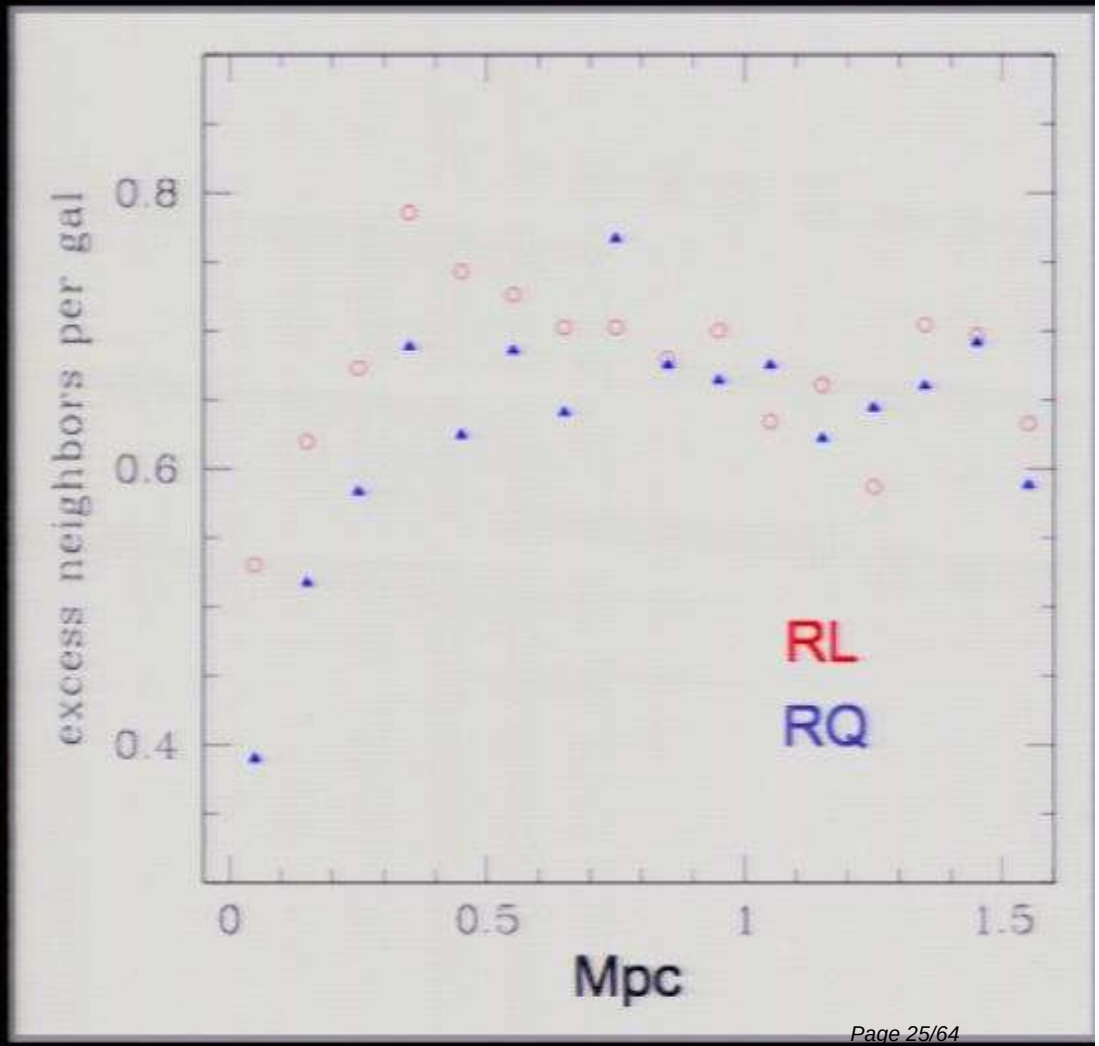




- RG distribution much more concentrated than galaxies
- in terms of NFW profile
  - galaxies: c~4
  - RGs: c~60
- being centrally located, BCGs have higher probability of being radio-active

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 $-23.5 \leq M_i \leq -20.5$
- within ~0.5 Mpc, RL galaxies always have higher number of neighbors than RQ ones



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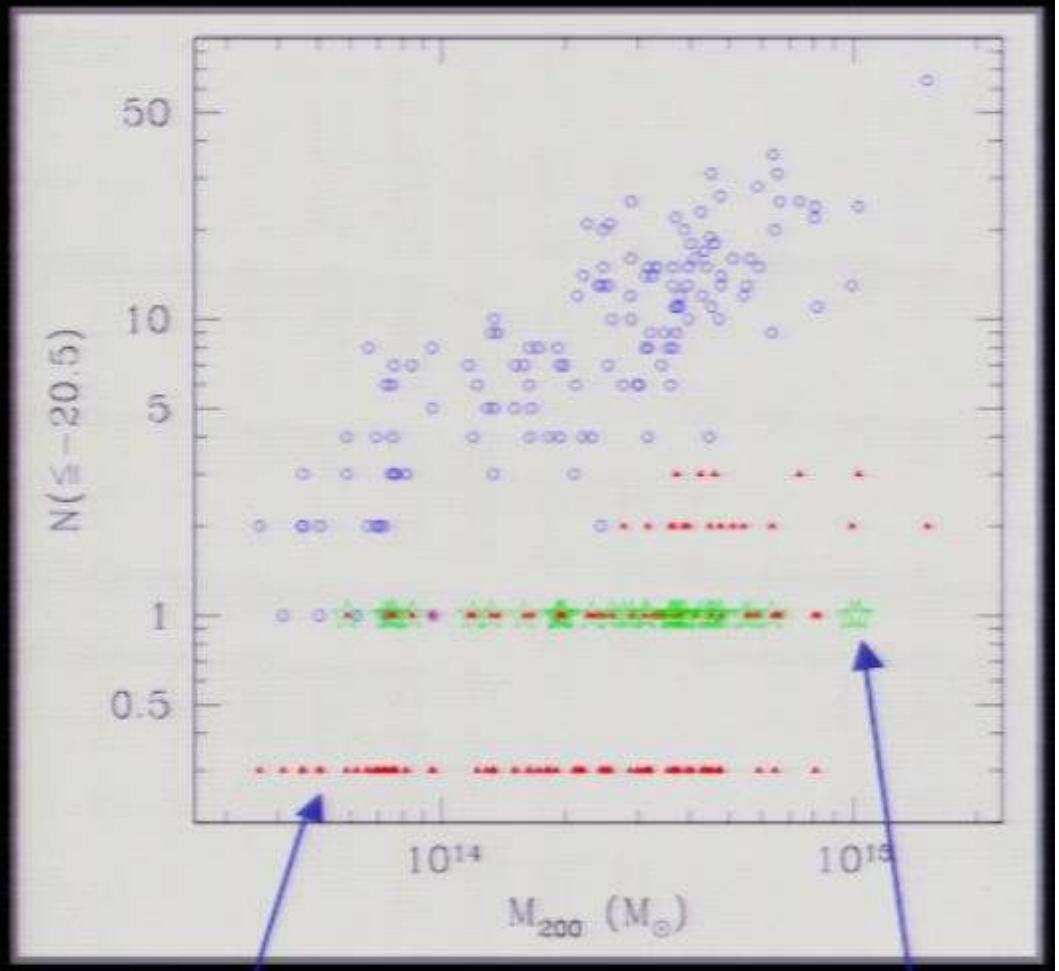

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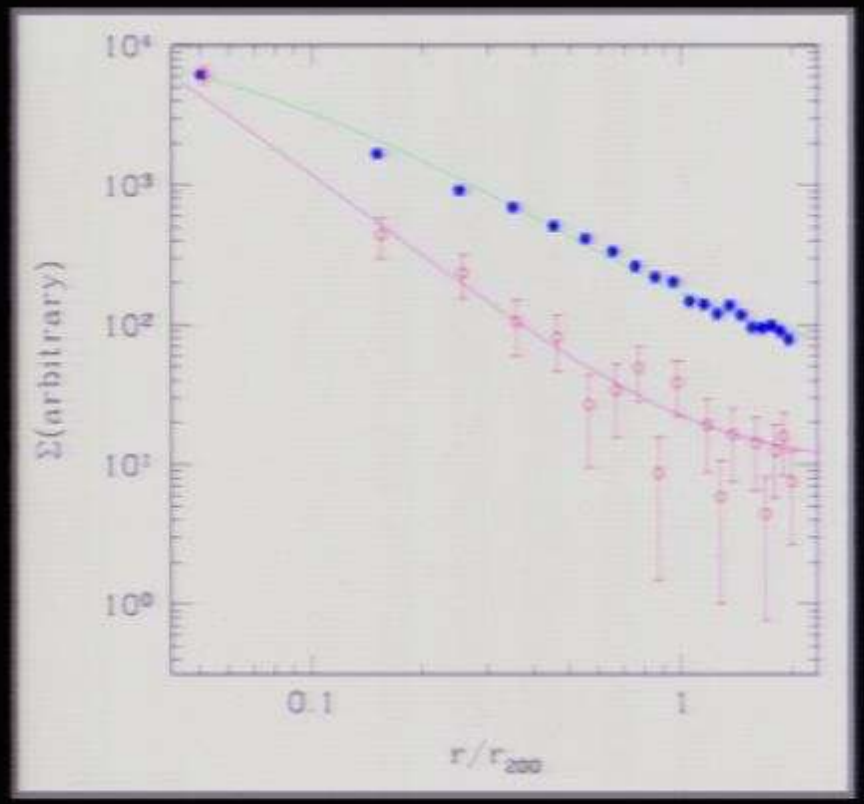

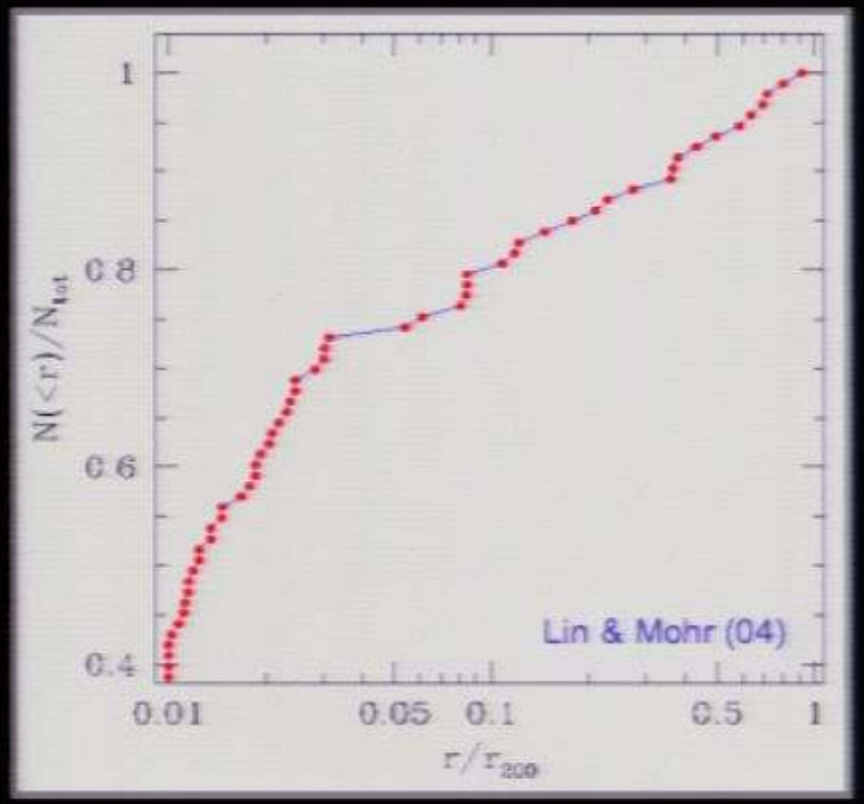

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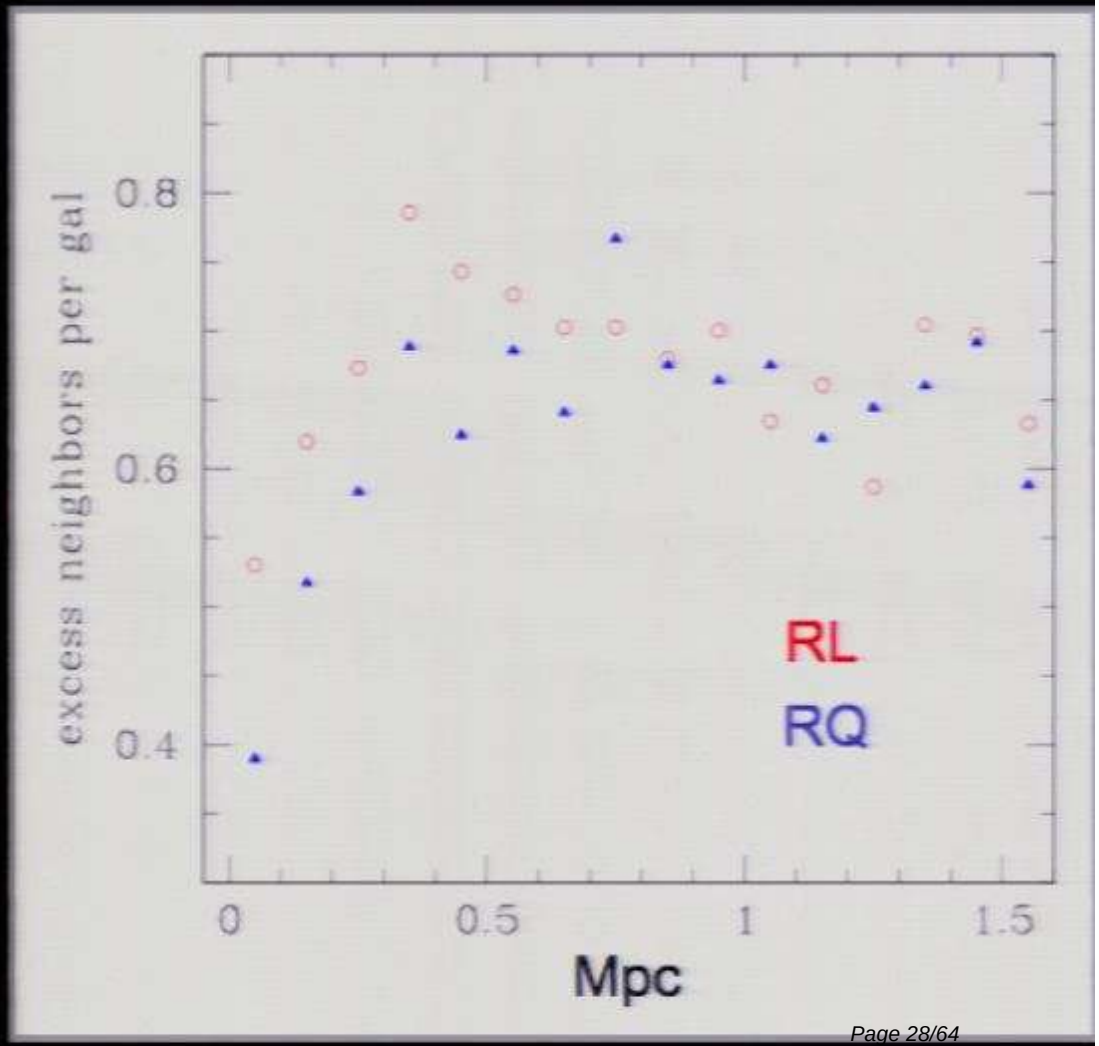

spectral energy distribution of radio sources in nearby clusters

- 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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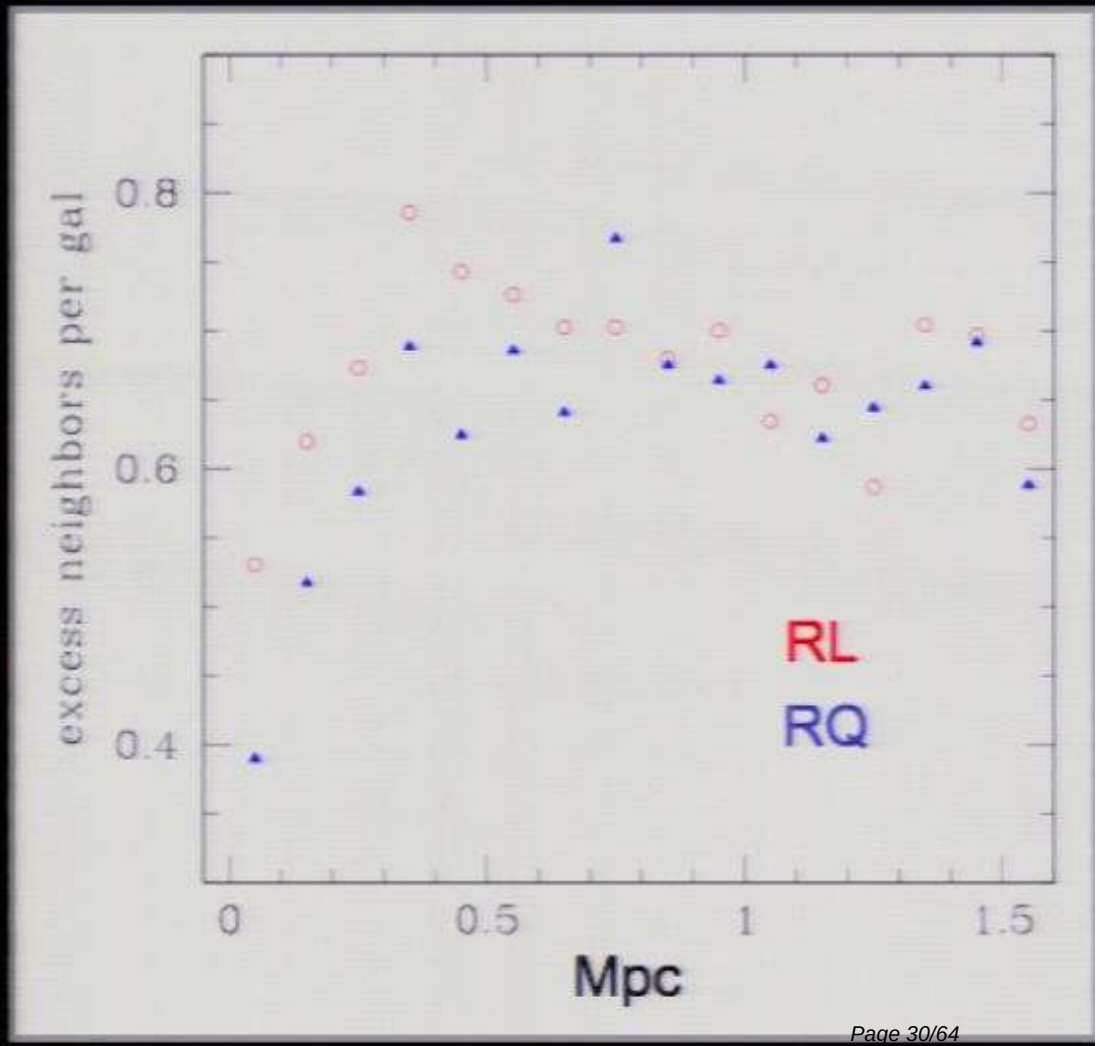

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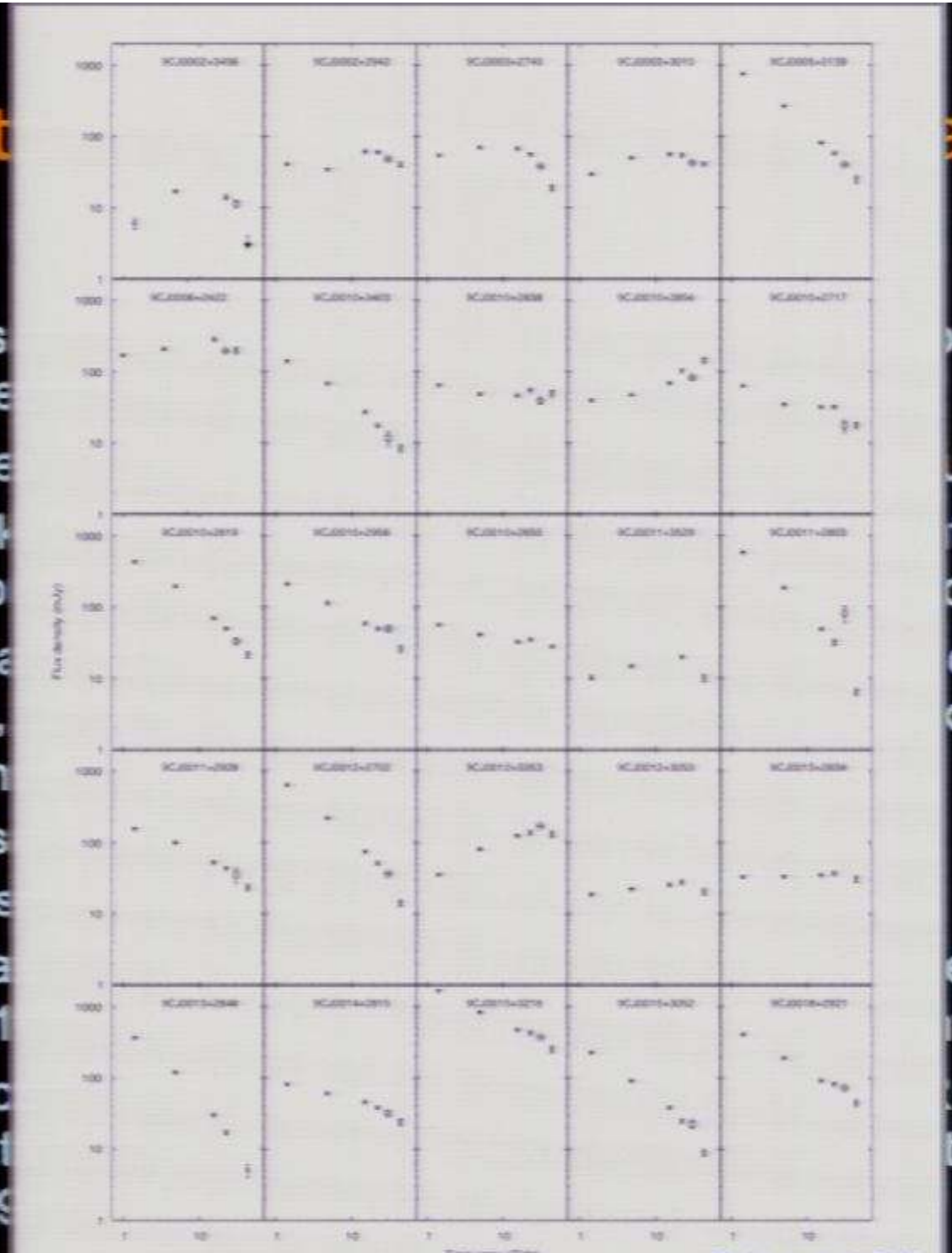

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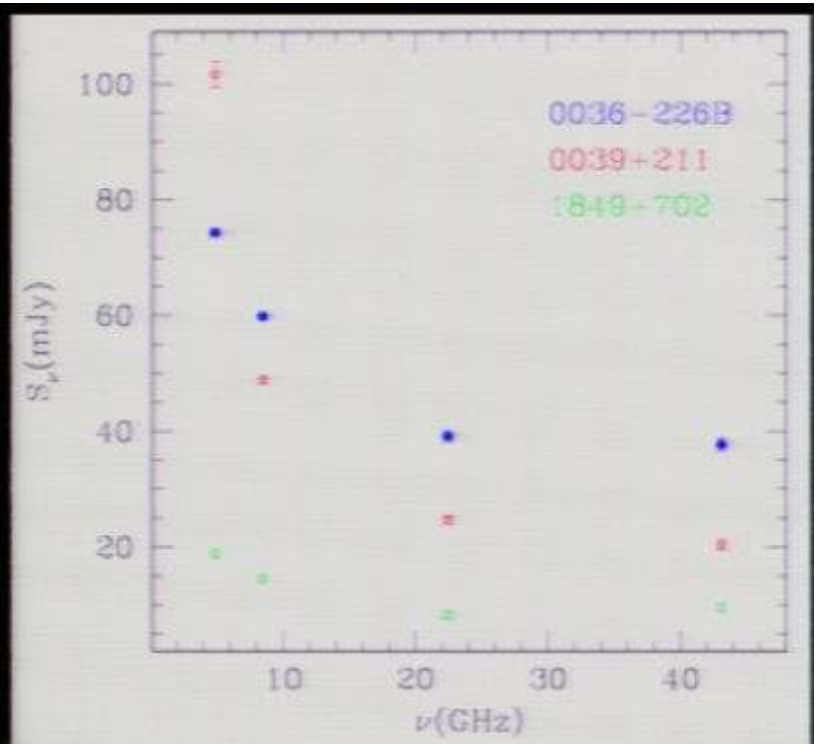
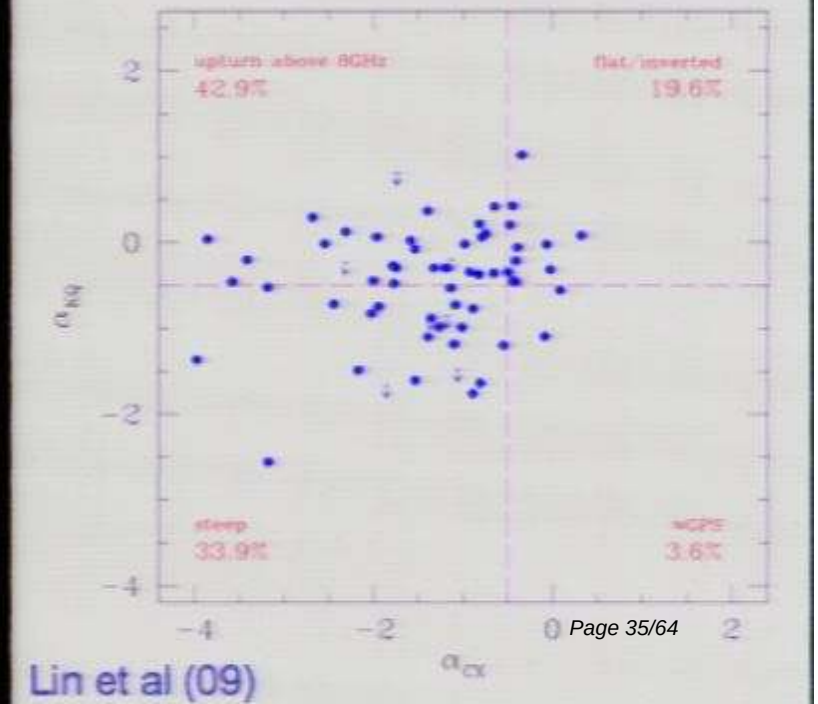
sample selection and observations

- Ledlow & Owen (1995,1996) conducted a 1.4 GHz survey of radio galaxies in ~400 Abell clusters at $z \leq 0.25$, 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

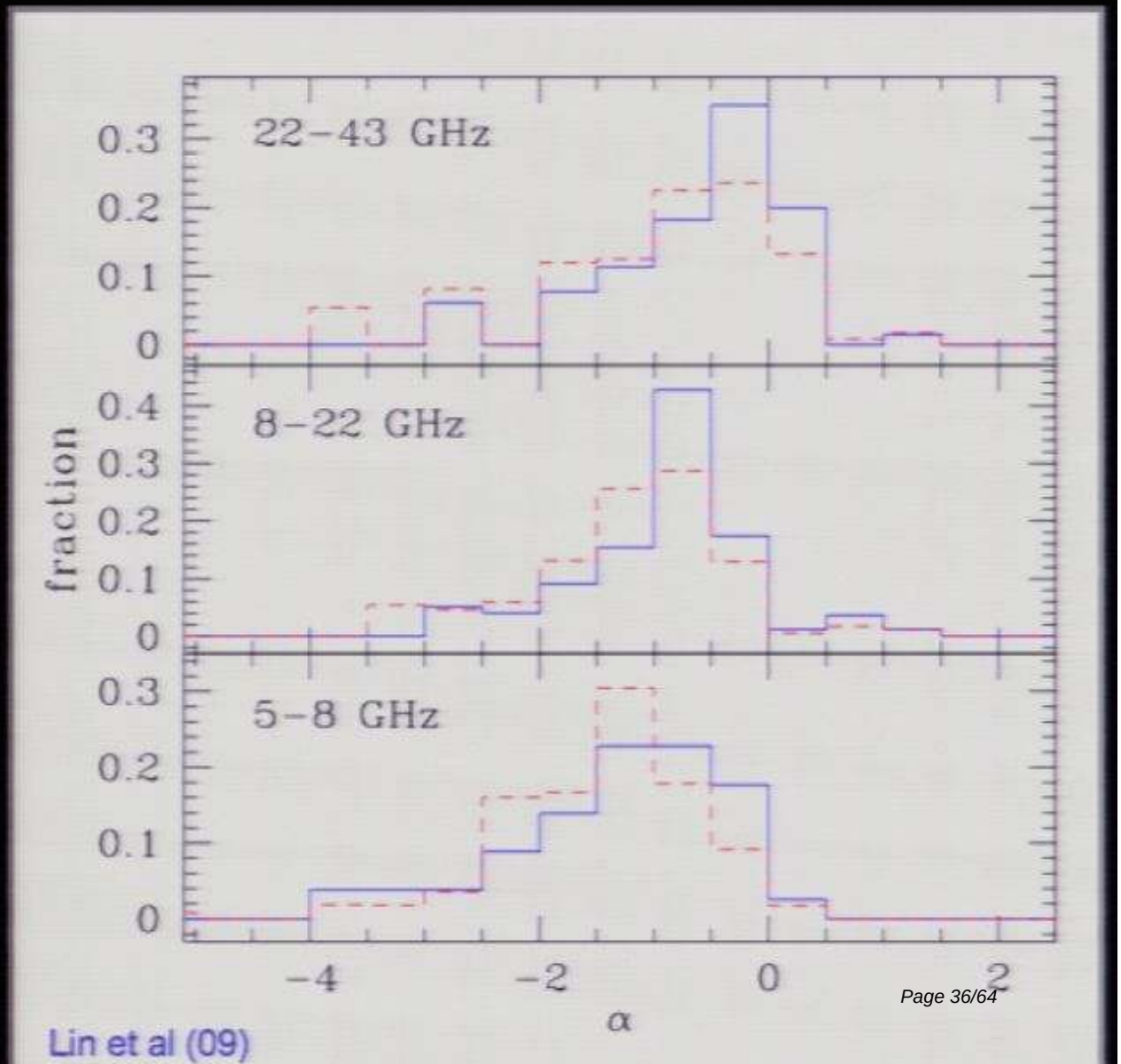




Lin et al (09)

spectral index distribution

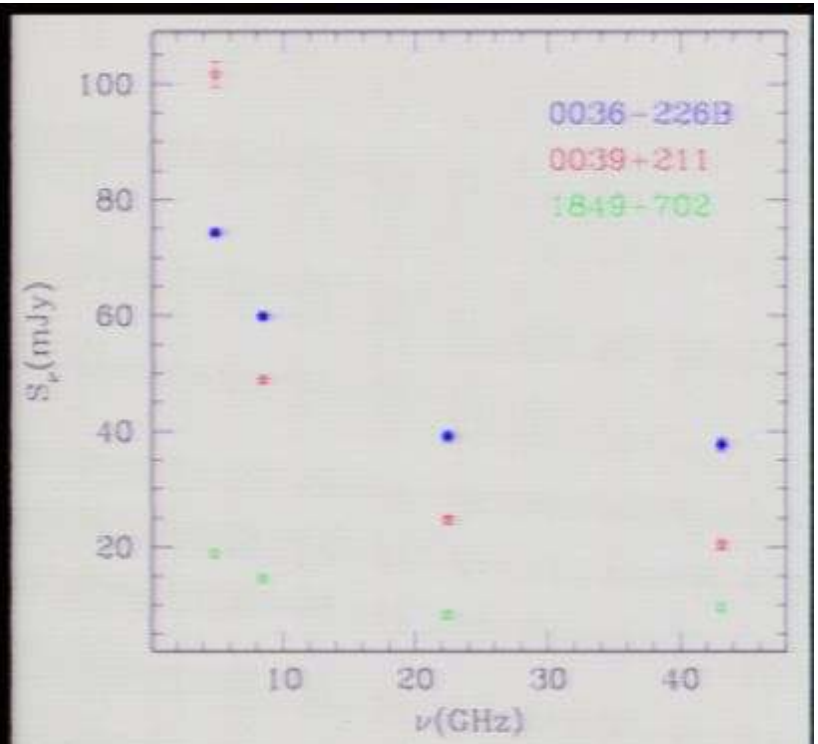
- solid histogram: core/point-like sources
- dashed histogram: all sources
- spectral indices α_{cx} and α_{xk} would be lower limits

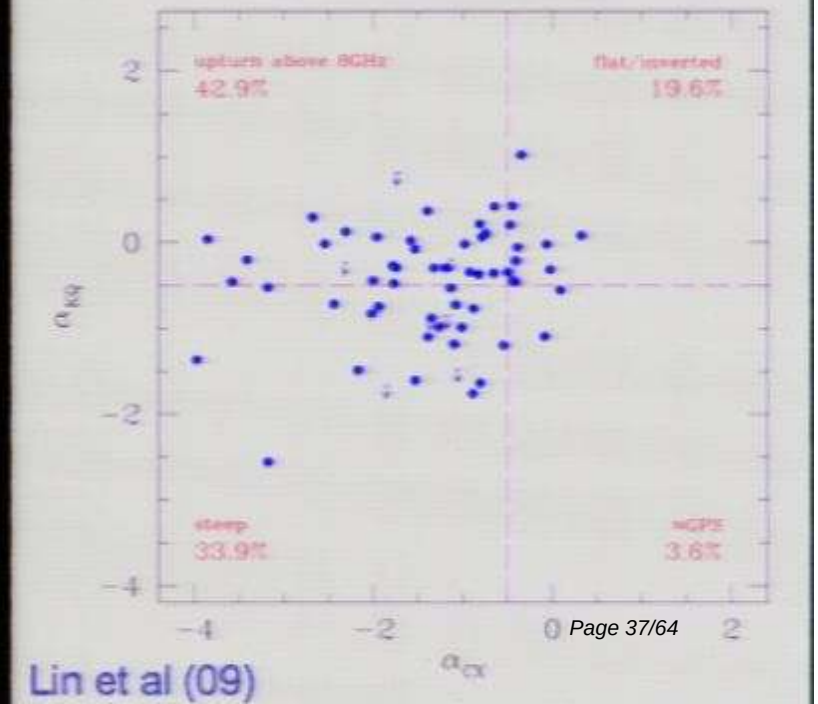


Lin et al (09)

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





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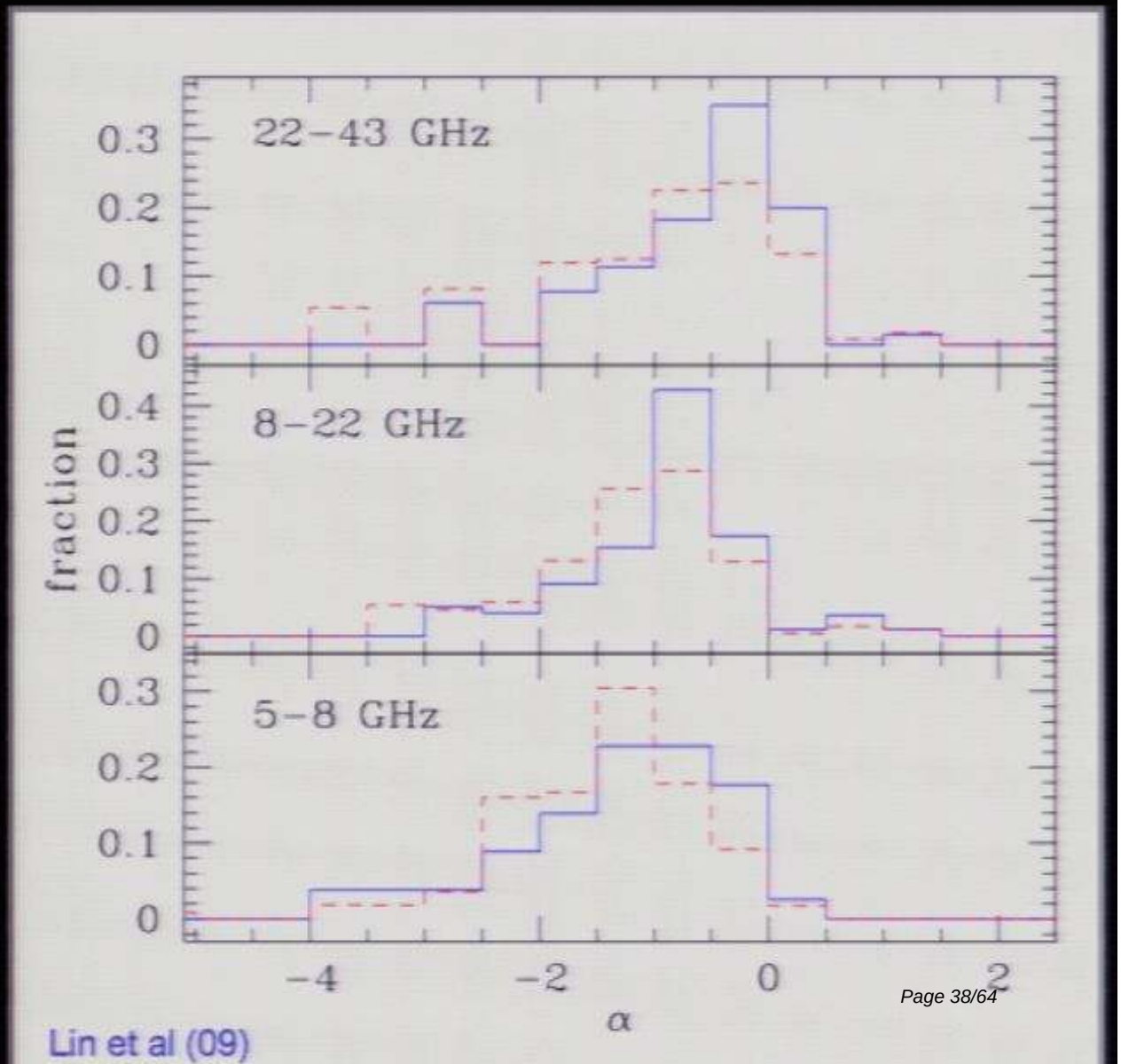

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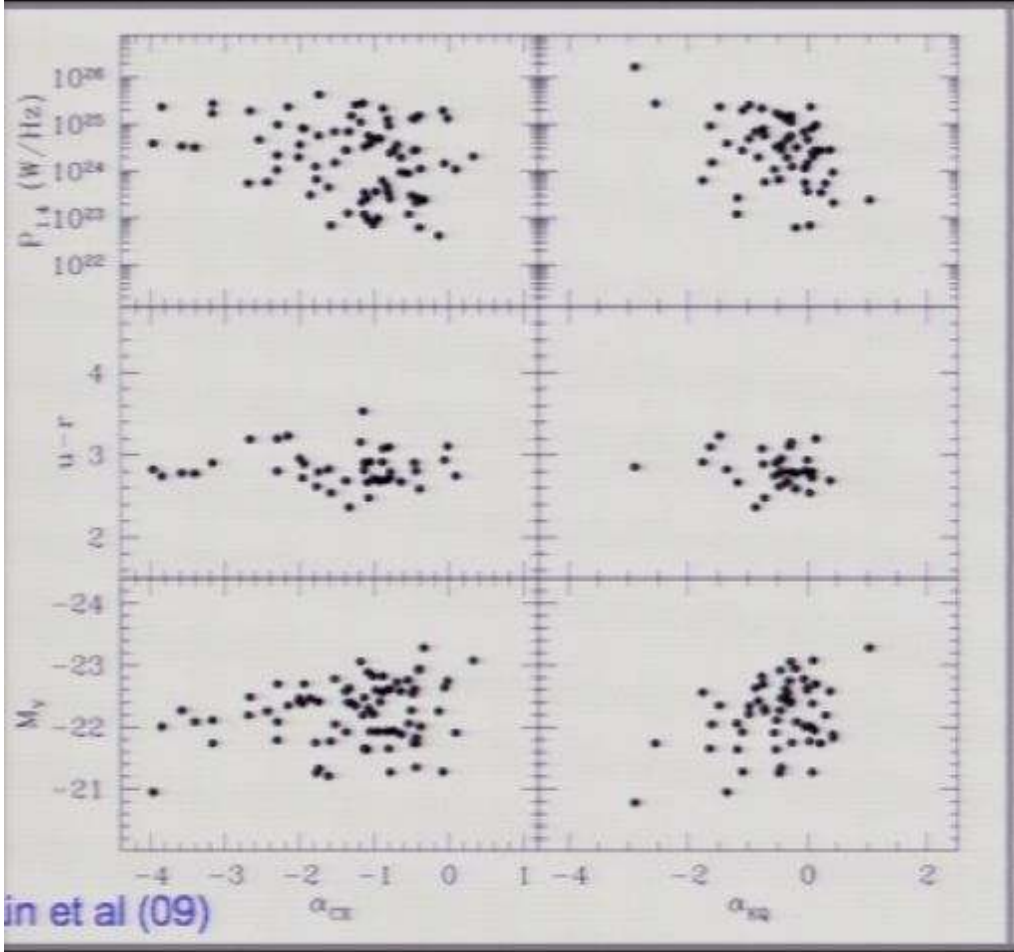
SID vs host galaxy/cluster properties



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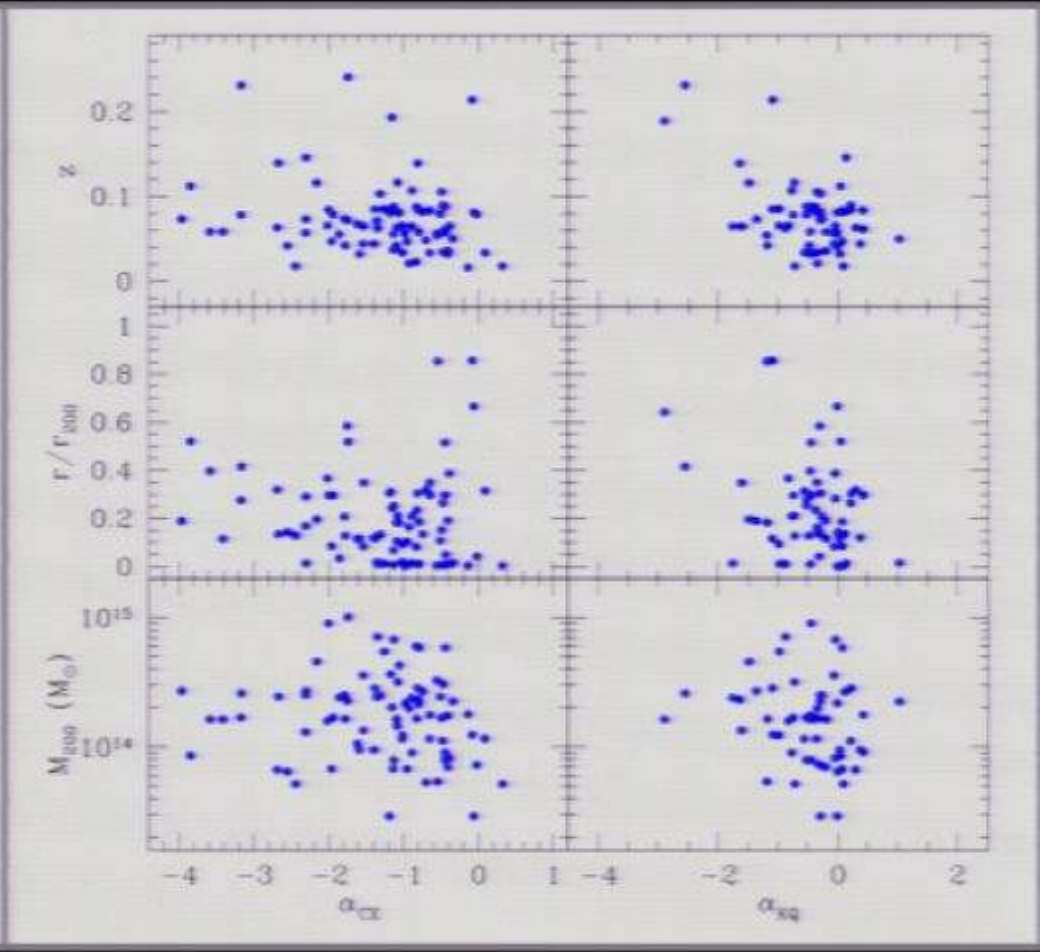

- no obvious correlation with optical luminosity, color, radio power of host galaxies
- no obvious correlation with redshift and mass of host clusters, and cluster-centric distance

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
- results will be presented in Partridge et al (09)

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
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  - 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)
  - does not include star-forming galaxies
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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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image credit: Leahy, Bridle, Strom

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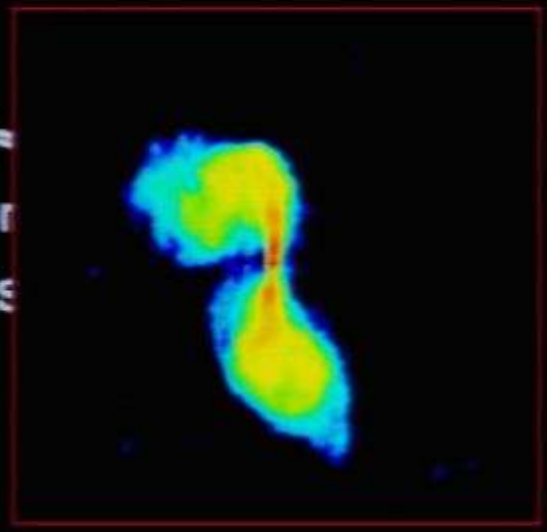

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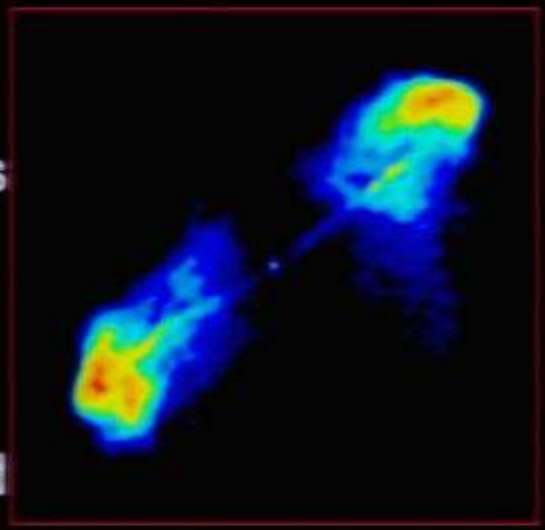

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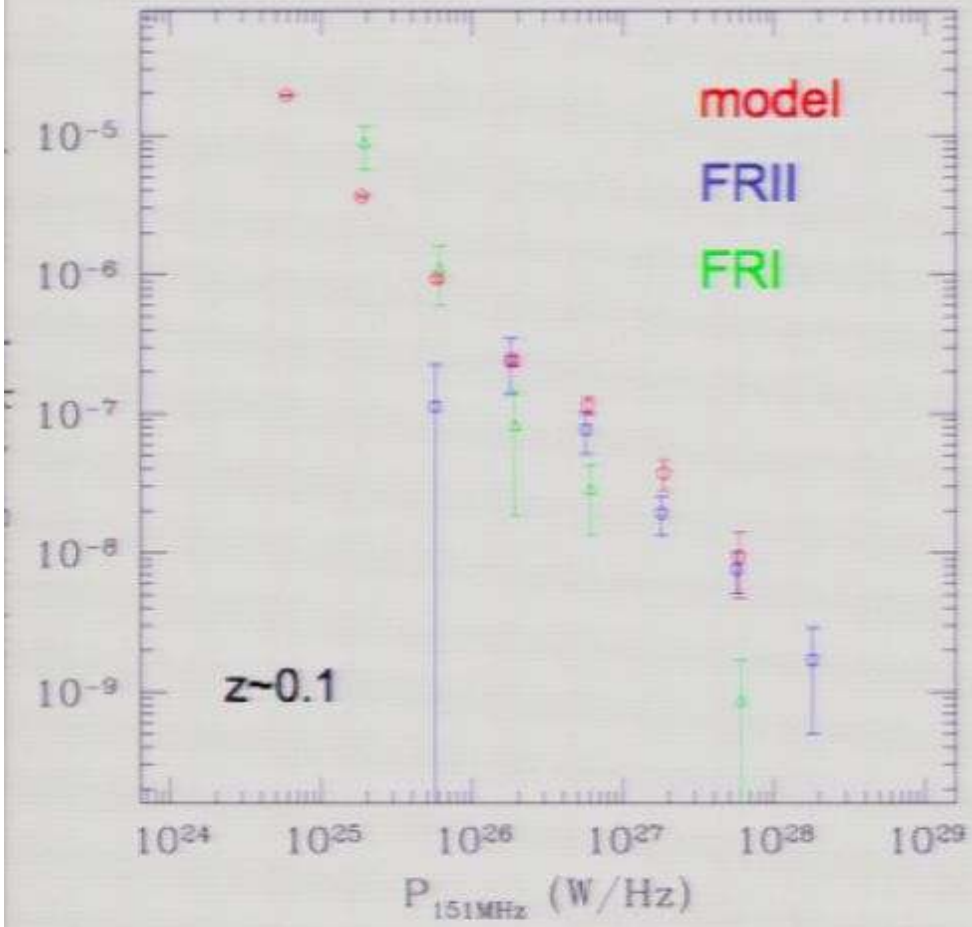
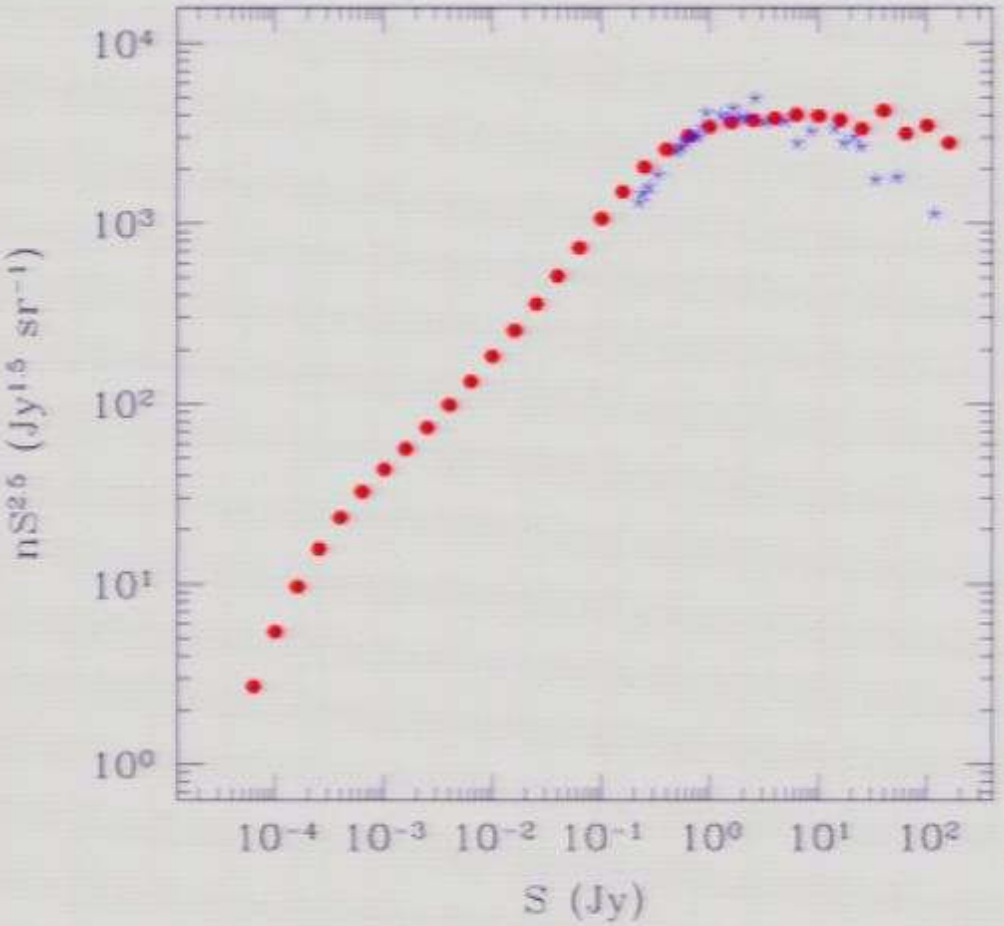
RLF and source count at 151 MHz





- draw radio luminosity from an assumed luminosity distribution
- tune HOD parameters so that 151 MHz RLF at z~0.1 is reproduced

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- set average SED of core component to reproduce the source counts at high-ν

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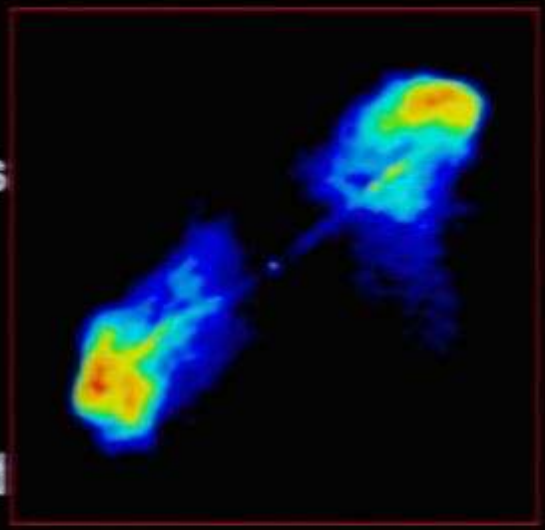

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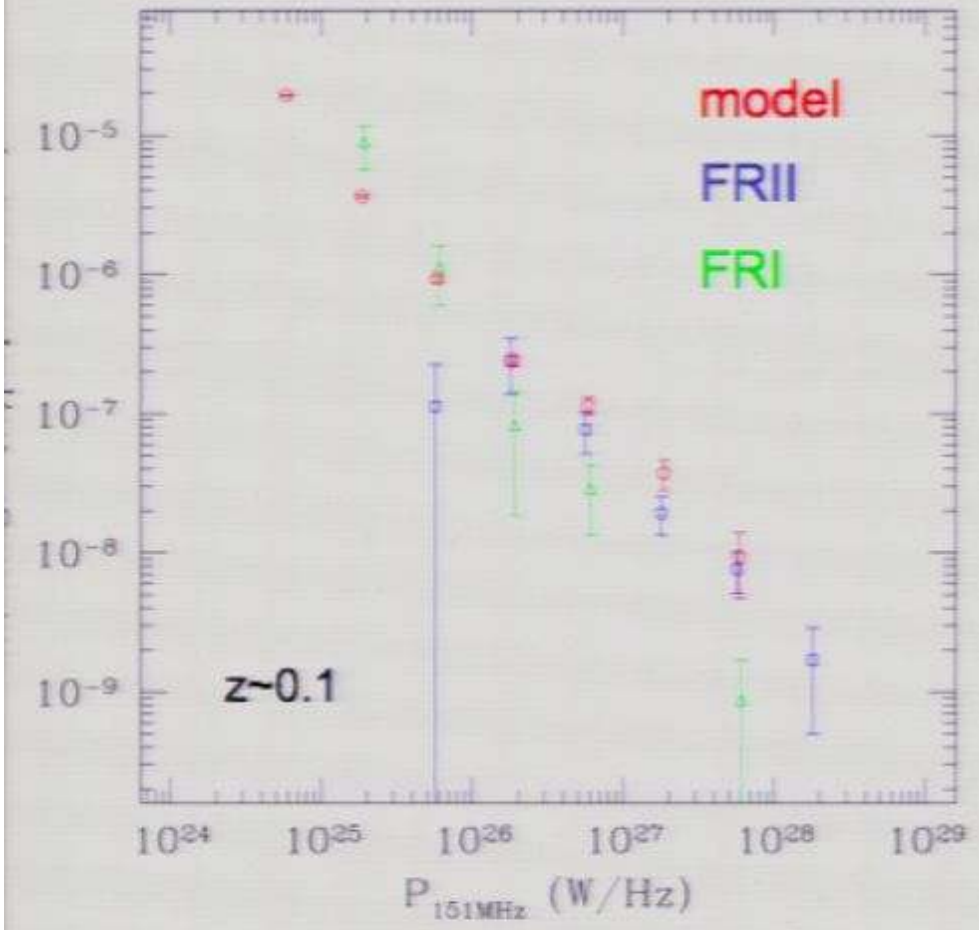

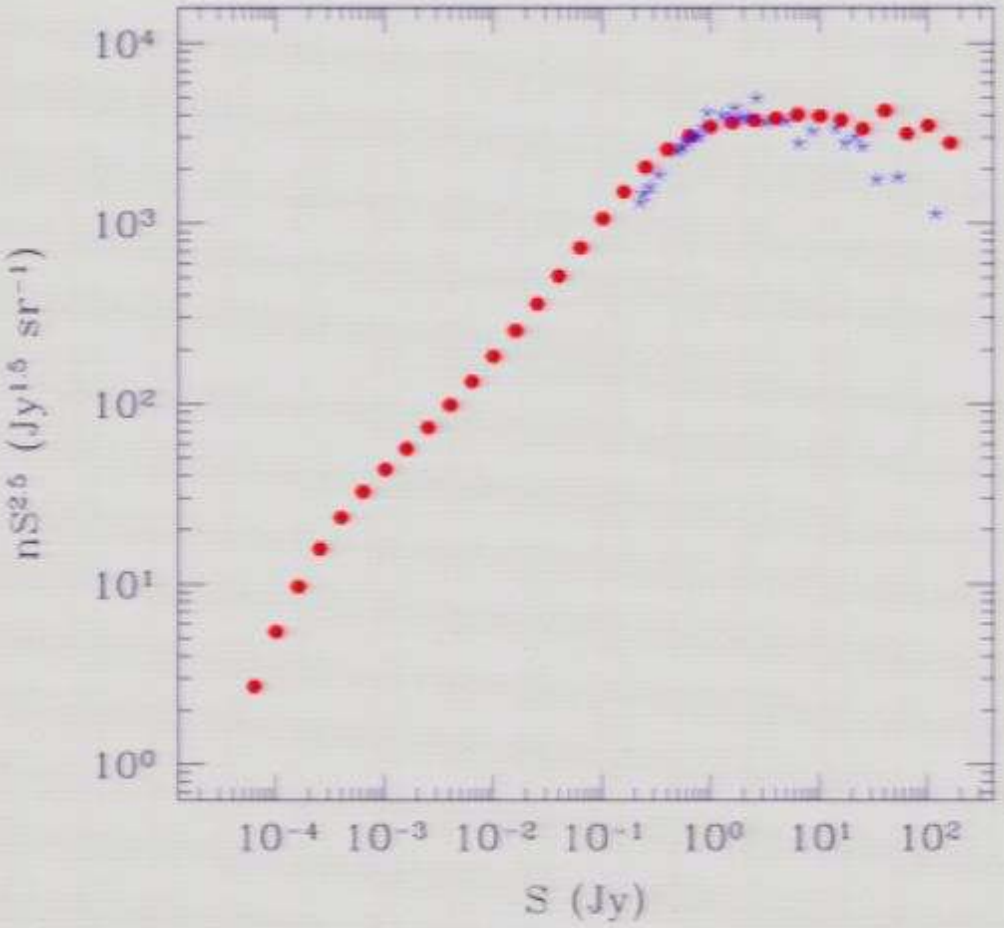

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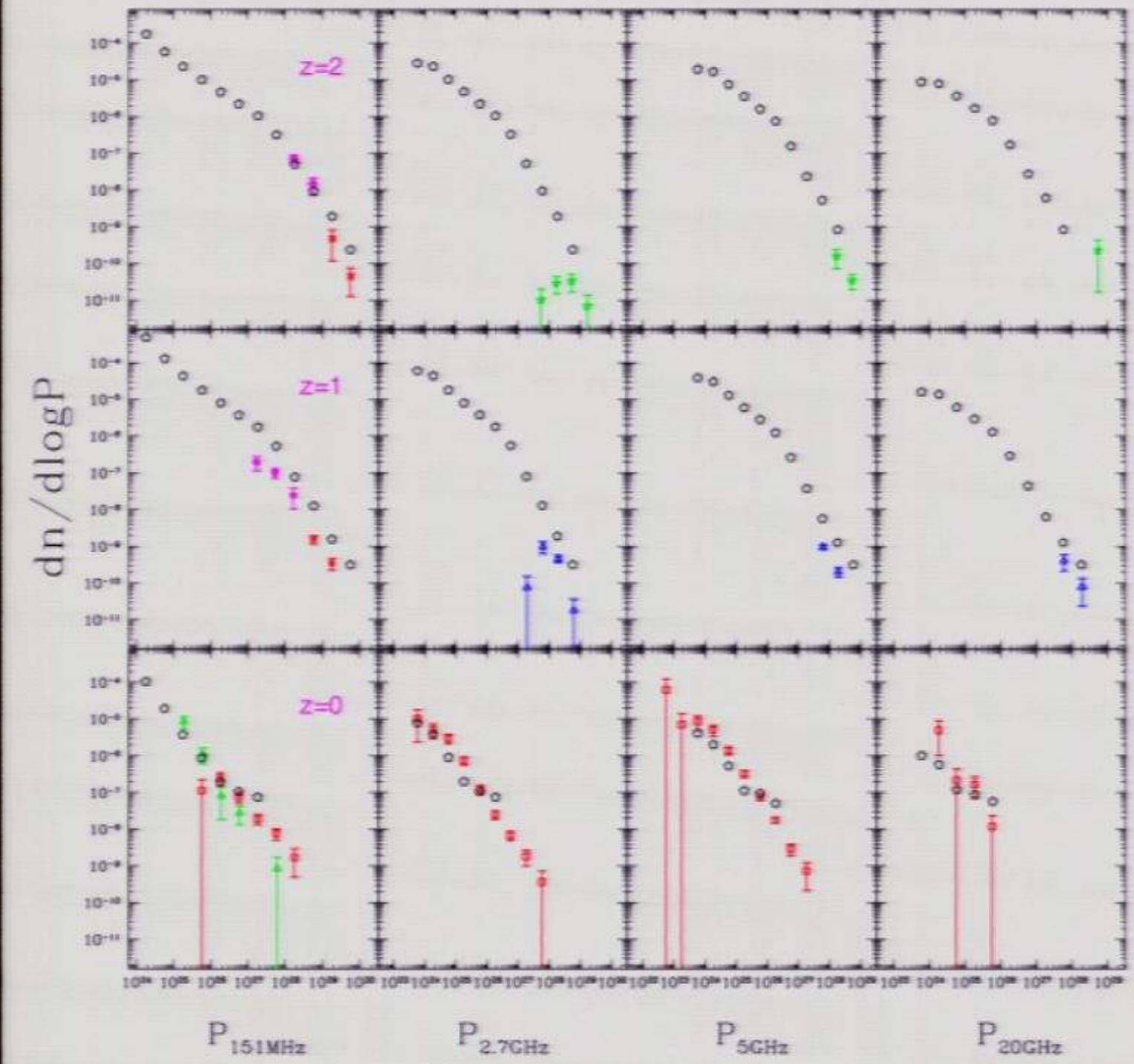
z=2
z=1
z=0
dn/dlogP
P 151MHz
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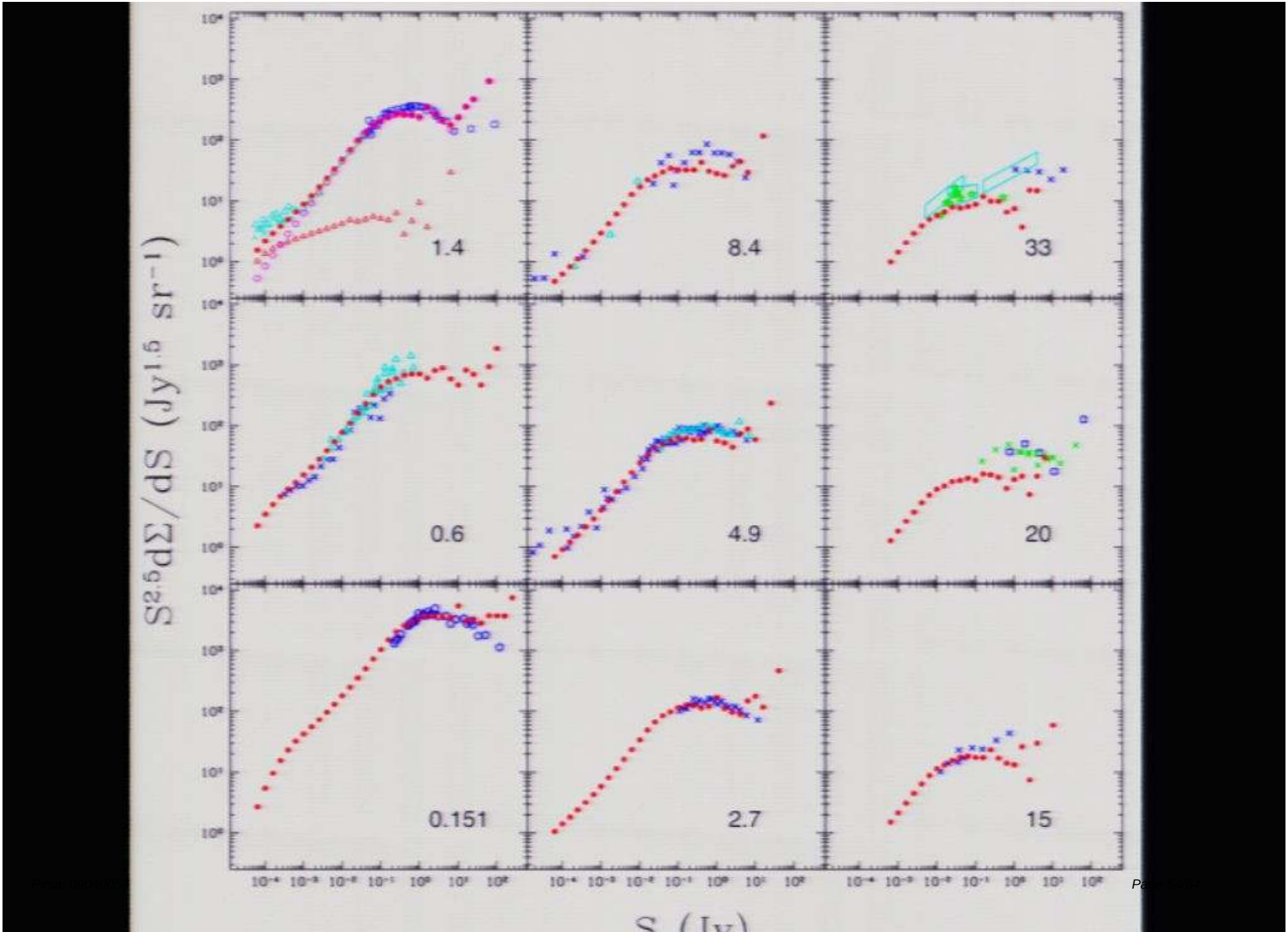
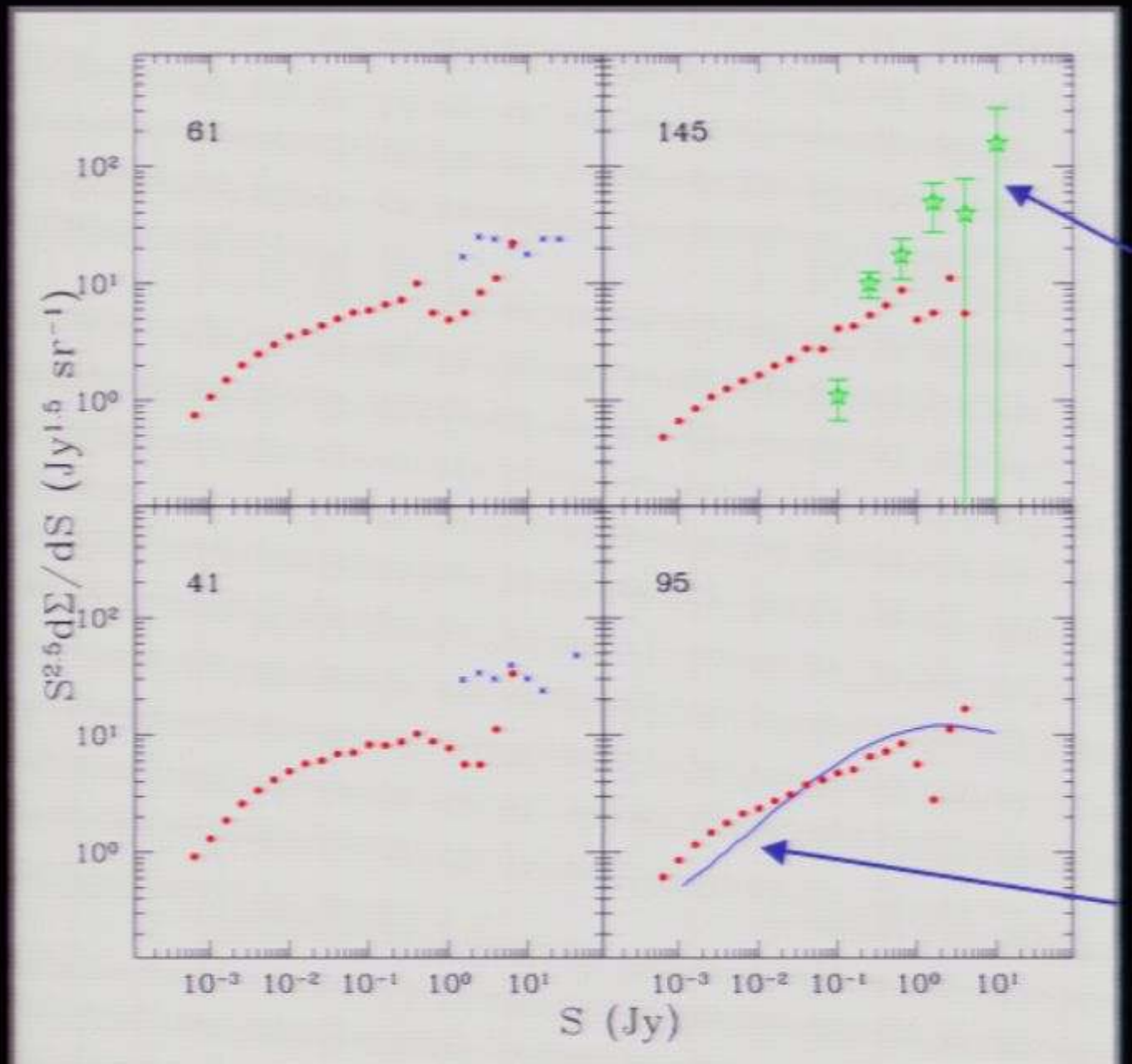
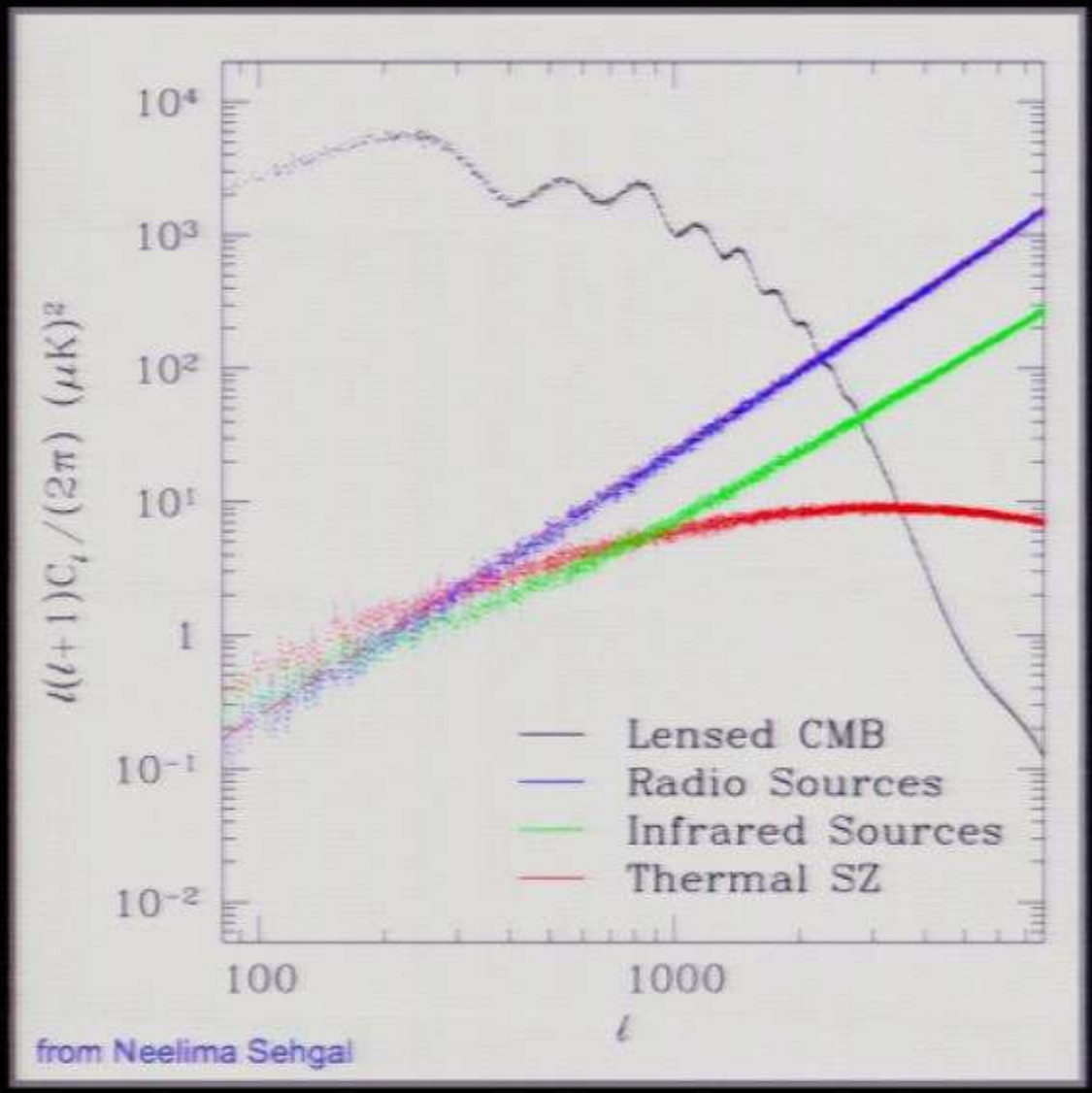

1.4
8.4
33
0.6
4.9
20
0.151
2.7
15
$S^{2.5}d\Sigma/dS$ (Jy$^{1.5}$ sr^{-1})
S (Jy)

high frequency source counts



power spectrum of model sources

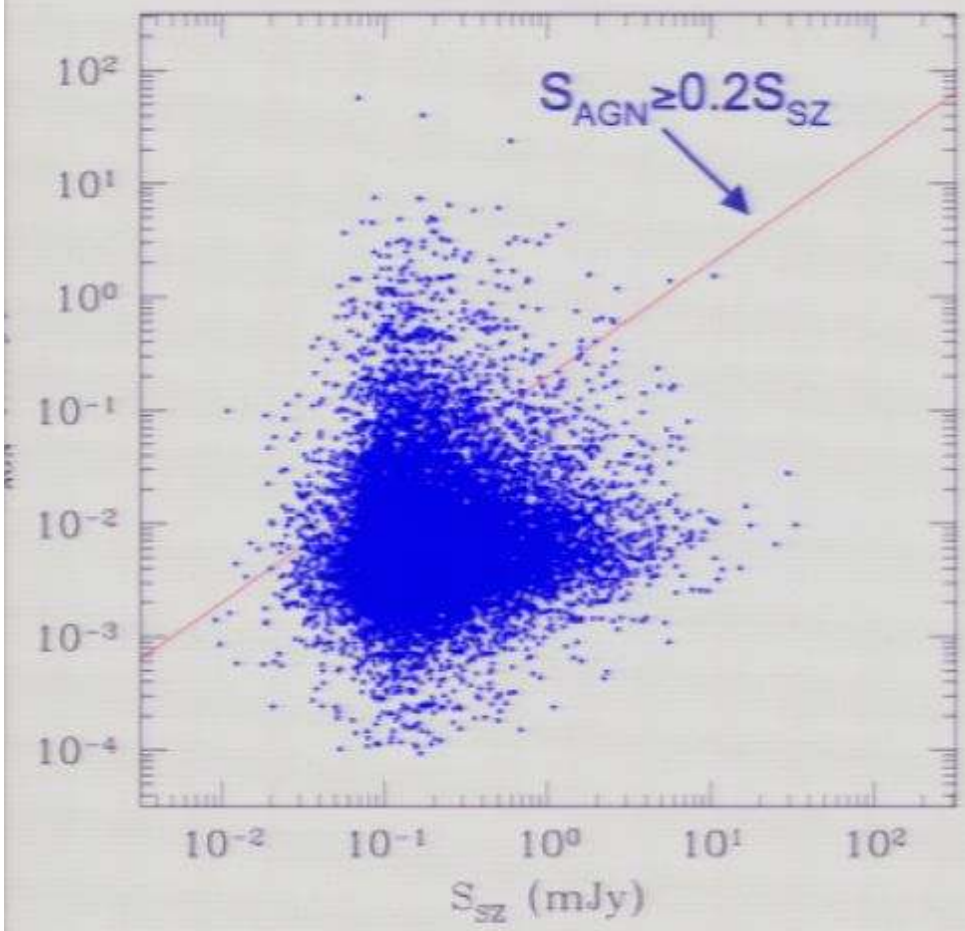


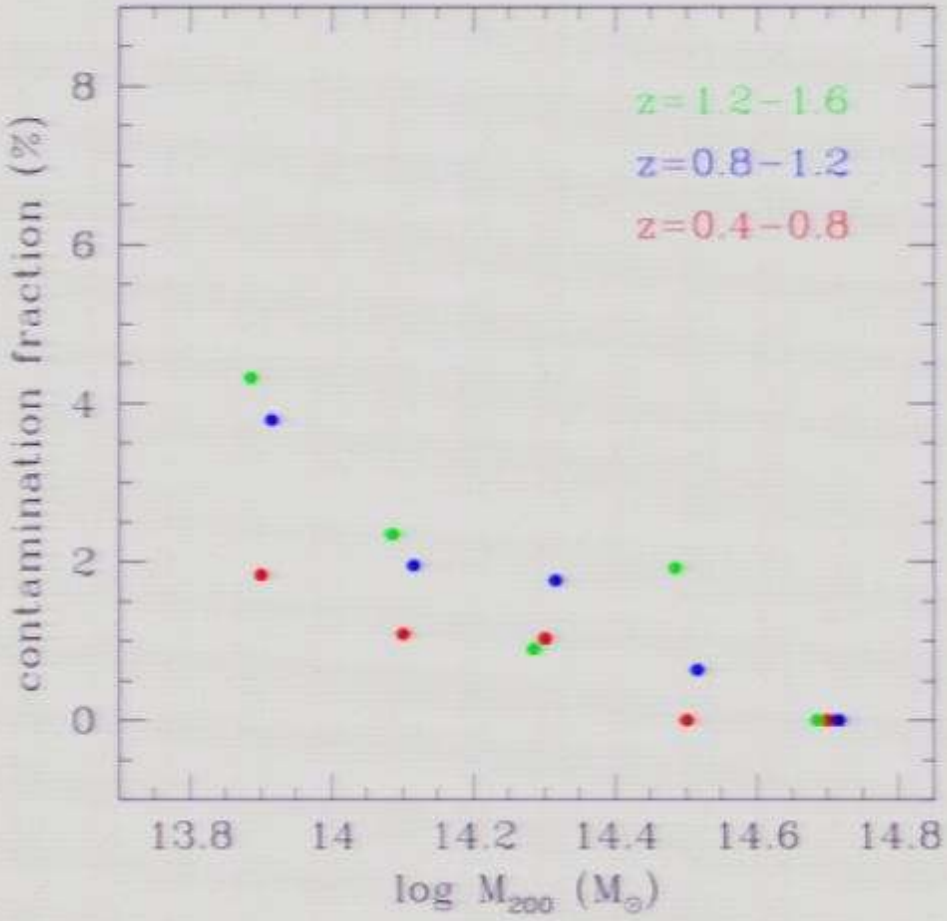
- power spectrum at 148 GHz agrees with the Toffolatti/de Zotti model (x0.64)

model parameters

- best parameters may not be unique
- limitation imposed by halo catalog ($z \lesssim 3$, 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 $z \lesssim 0.8$, $\propto(1+z)^3$; 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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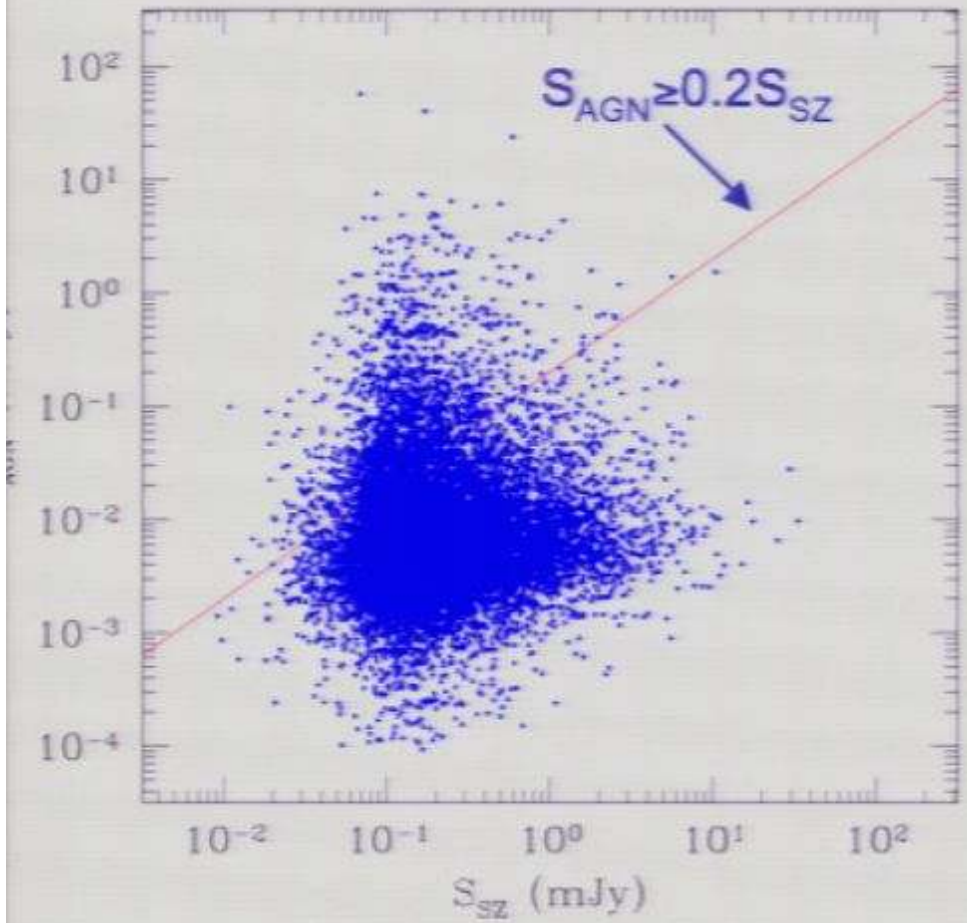

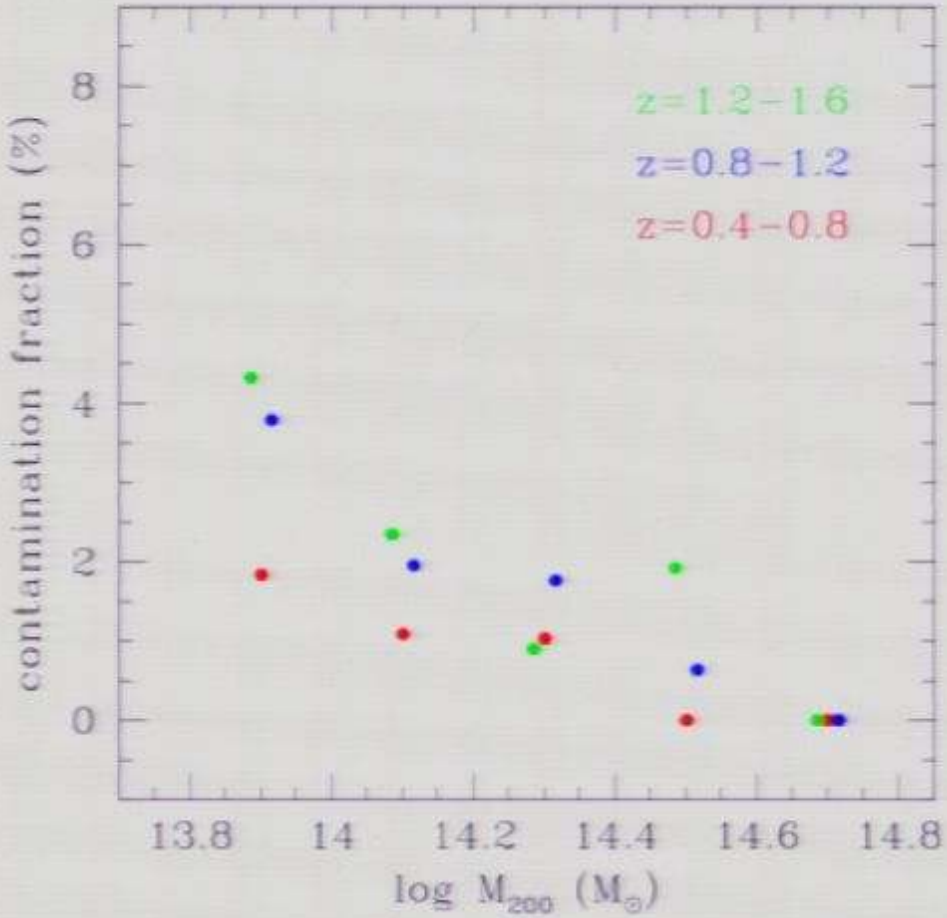

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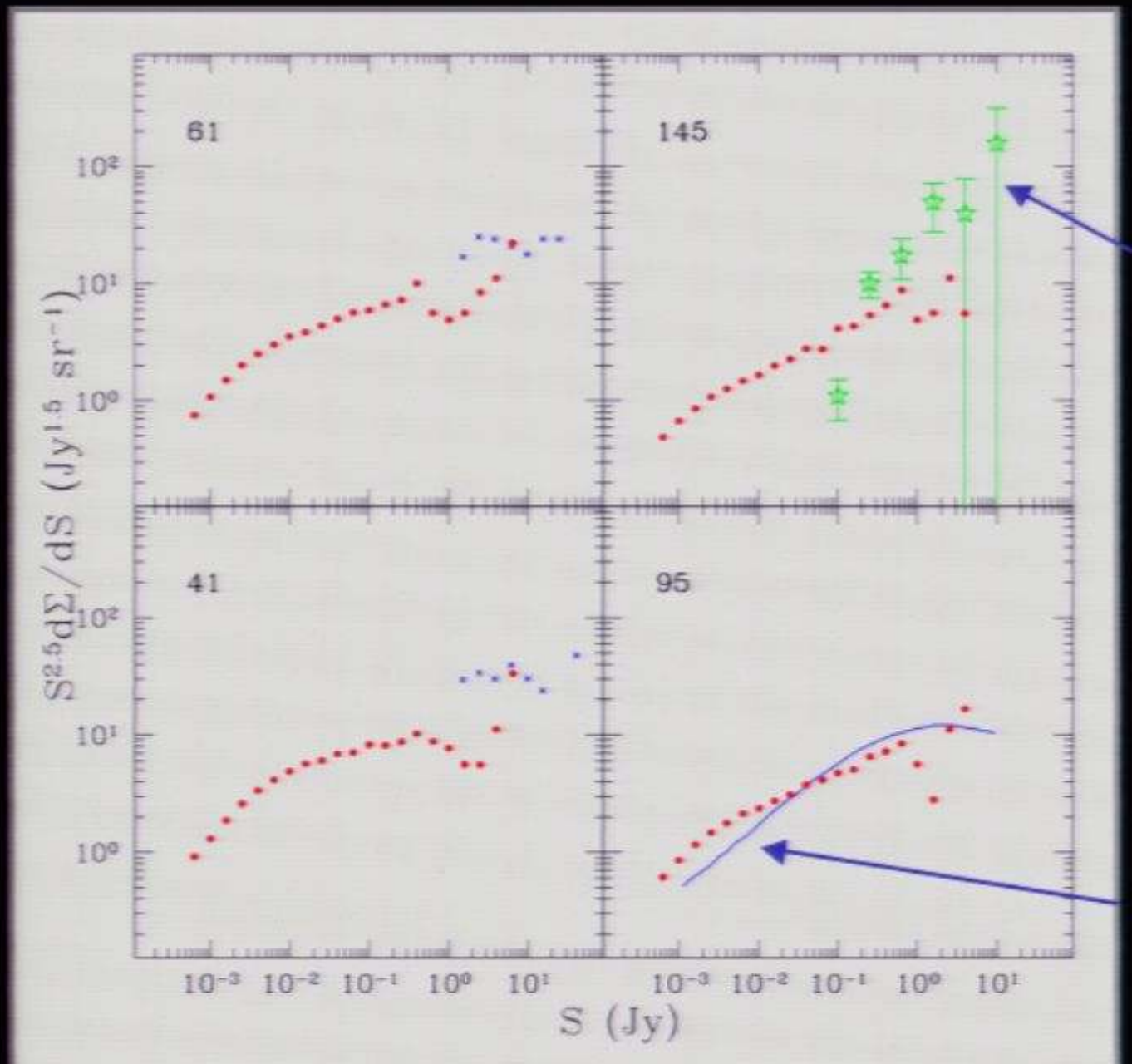

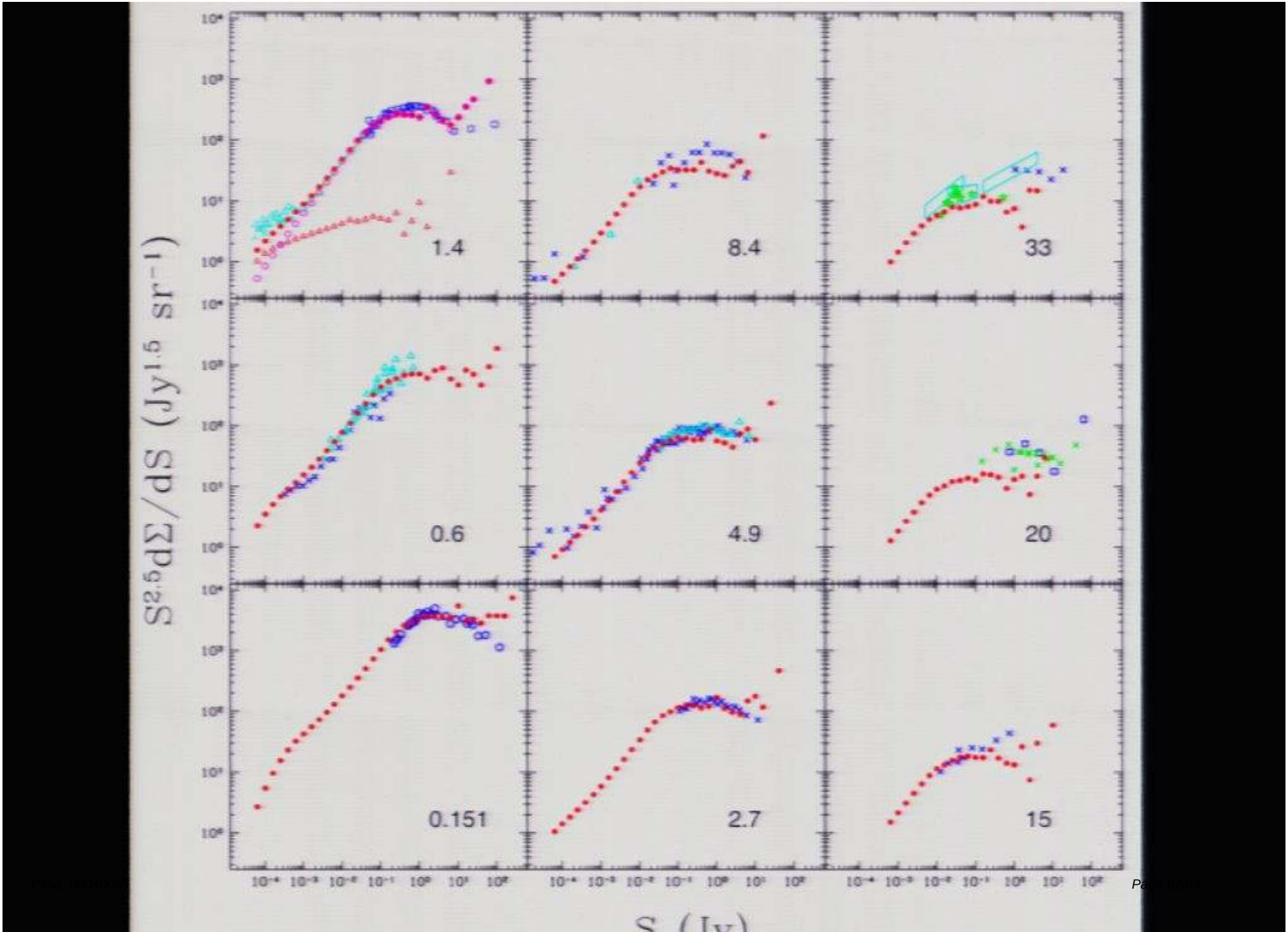
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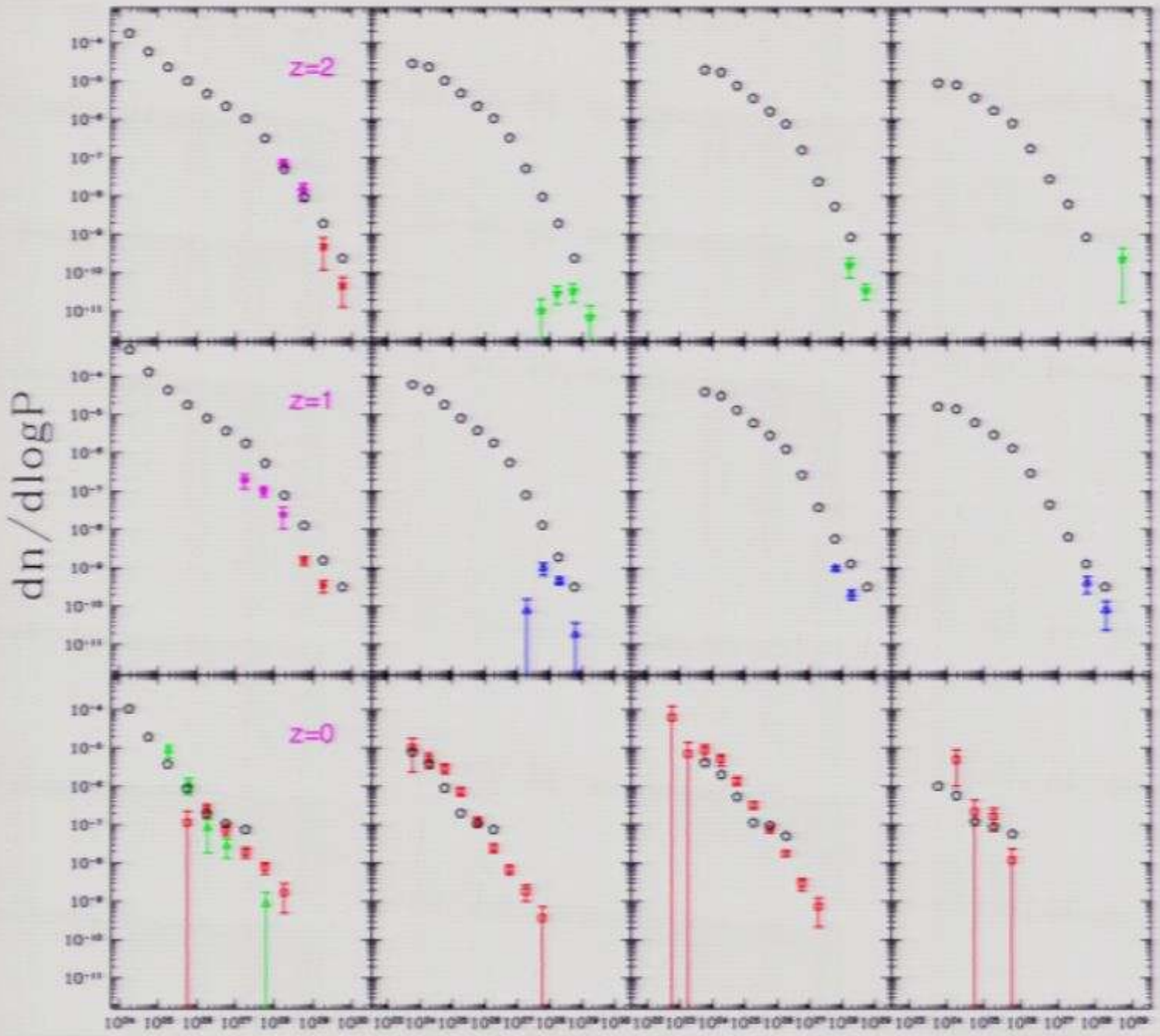
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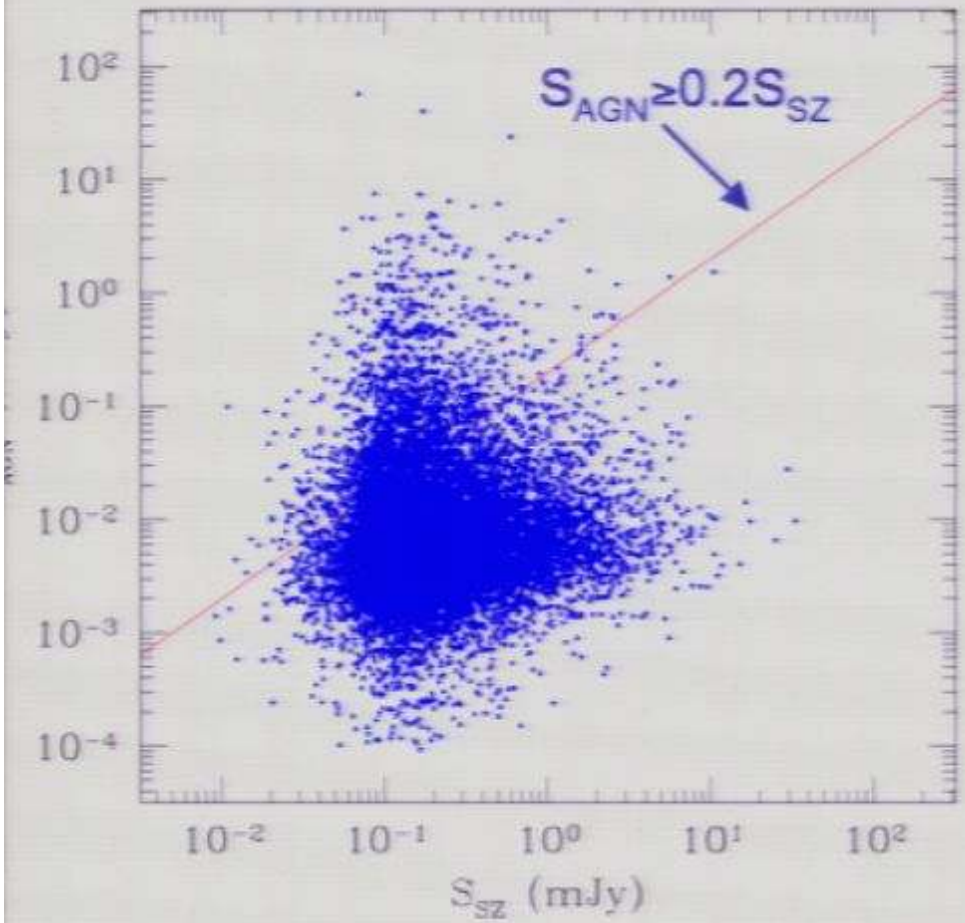

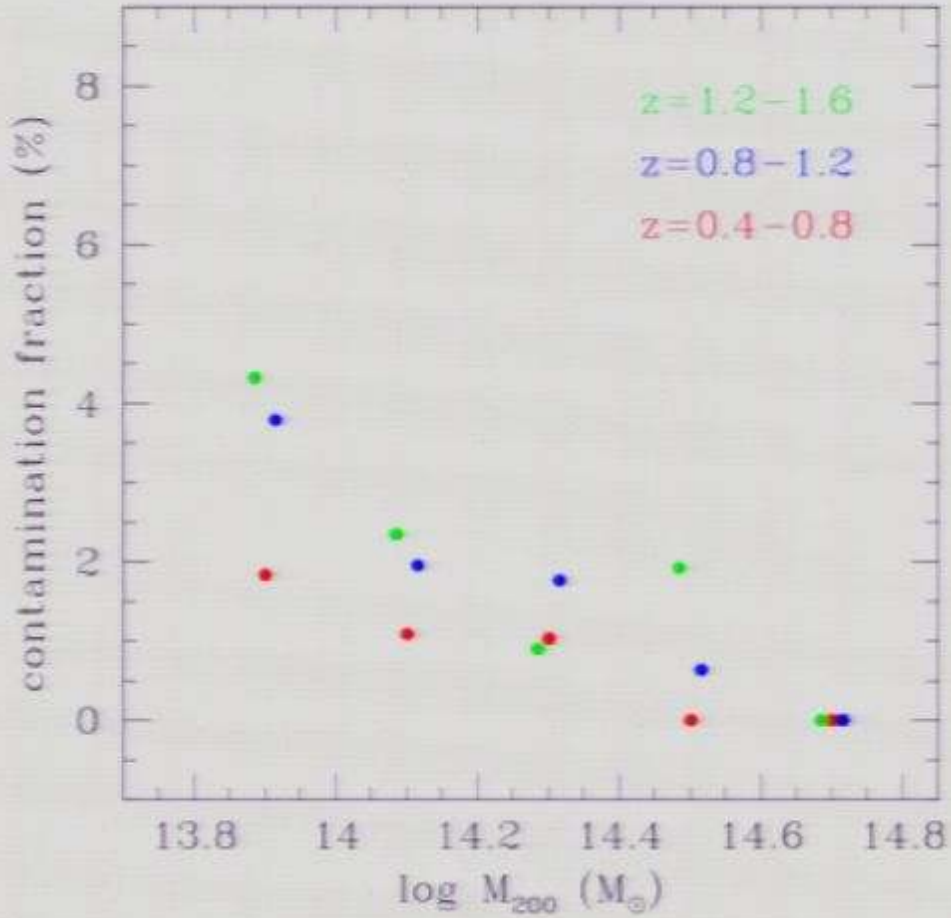

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