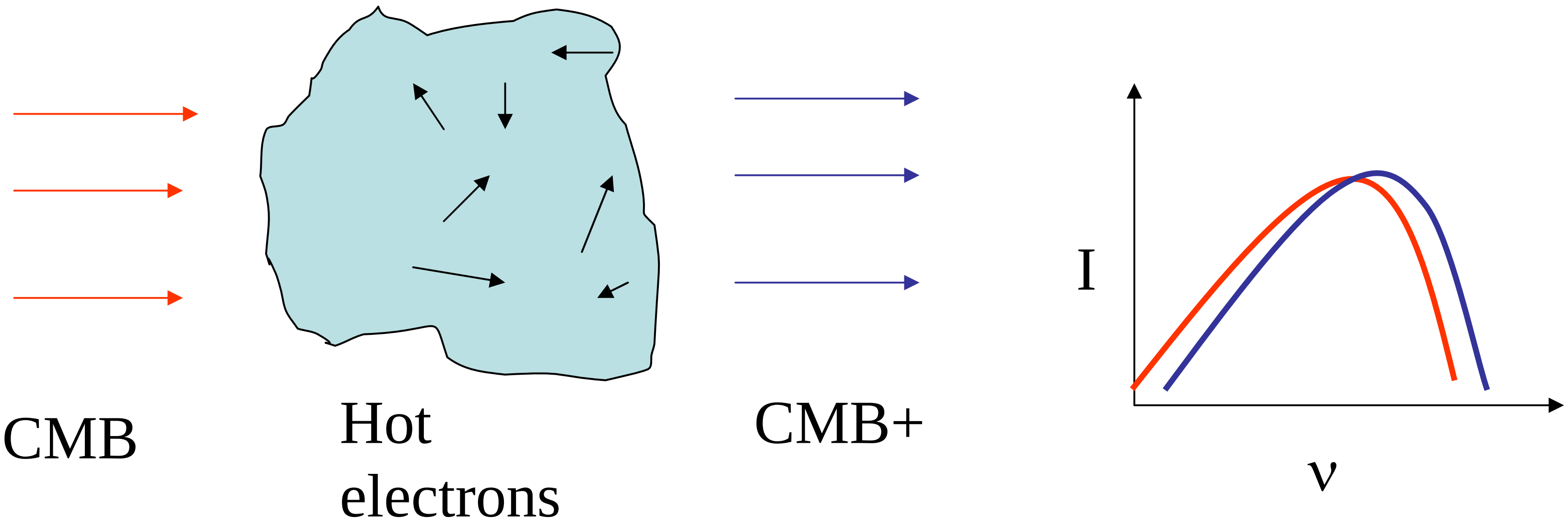
SZ Surveys: Source Detection & Catalog Construction, and Mass Estimates

Gil Holder

25 years cifar
Canadian Institute for Advanced Research

McGill

Thermal Sunyaev-Zel'dovich Effect



Optical depth: $\tau \sim 0.01$

Fractional energy gain per scatter: $\frac{kT}{m_e c^2} \sim 0.01$

Typical massive cluster signal: ~500 uK

SZ Observables I

Along a line of sight:

$$\frac{\Delta T}{T} = g(\nu)\int dl \left(\frac{kT}{m_e c^2}\right) n_e(l)\sigma_T$$

DEPENDS ONLY ON CLUSTER PROPERTIES !!!!

- Independent of redshift
- Temperature weighted electron column density
- Unique spectral signature

SZ Observables II

Integrated effect from cluster:

$$S \propto \int \Delta T \, d\Omega \propto \frac{1}{d_A(z)^2} \int n_e kT \, dV$$

- proportional to total thermal energy of electrons

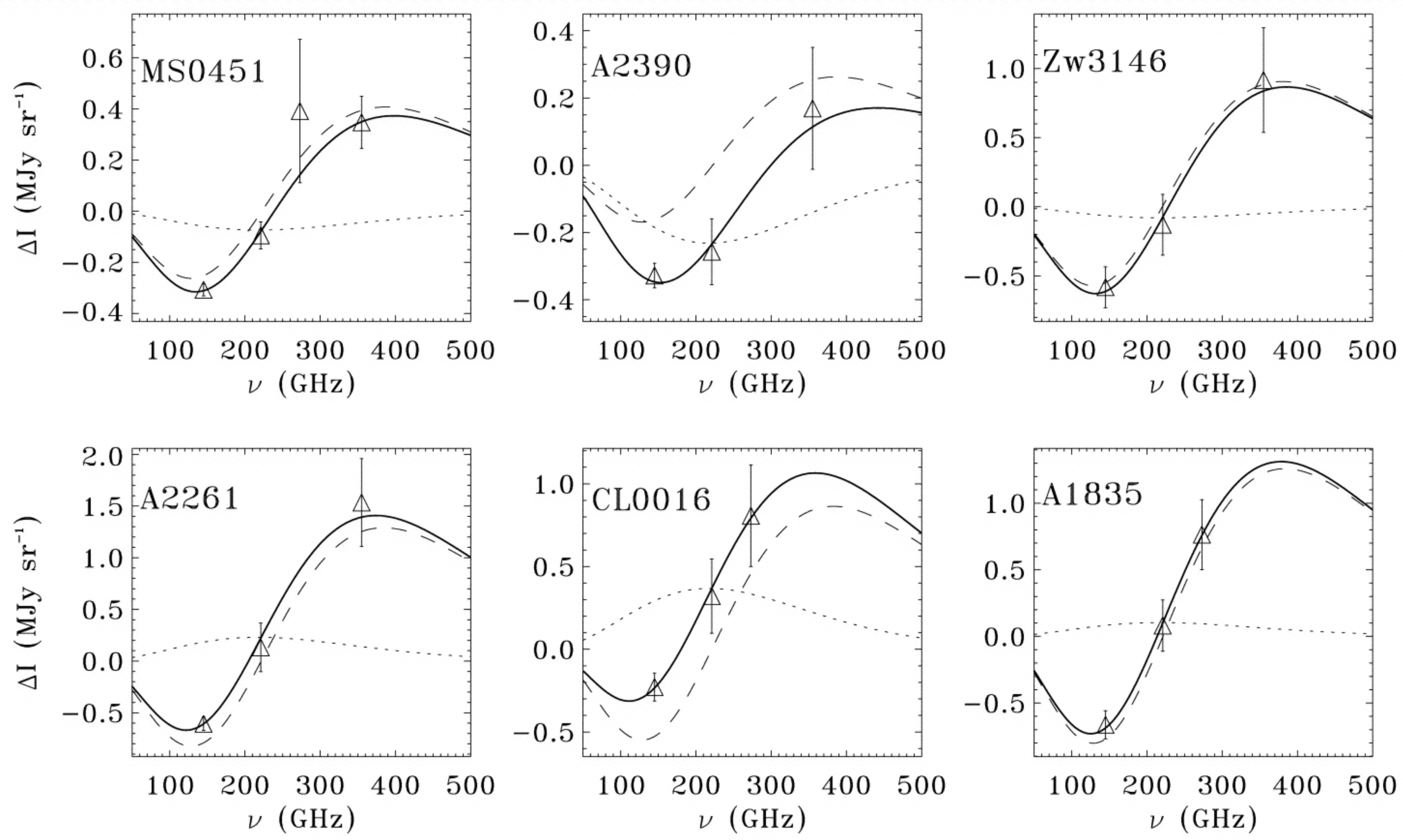
- angular diameter distance, not luminosity distance

Simple expectation:

$$S_{sz} = AM^{5/3}[\Delta(z)E^2(z)]^{1/3} d_A^{-2}(z)$$

$$S_{sz} \propto T^{5/2}[\Delta(z)E^2(z)]^{-1/2} d_A^{-2}(z)$$

Non-Thermal Spectrum

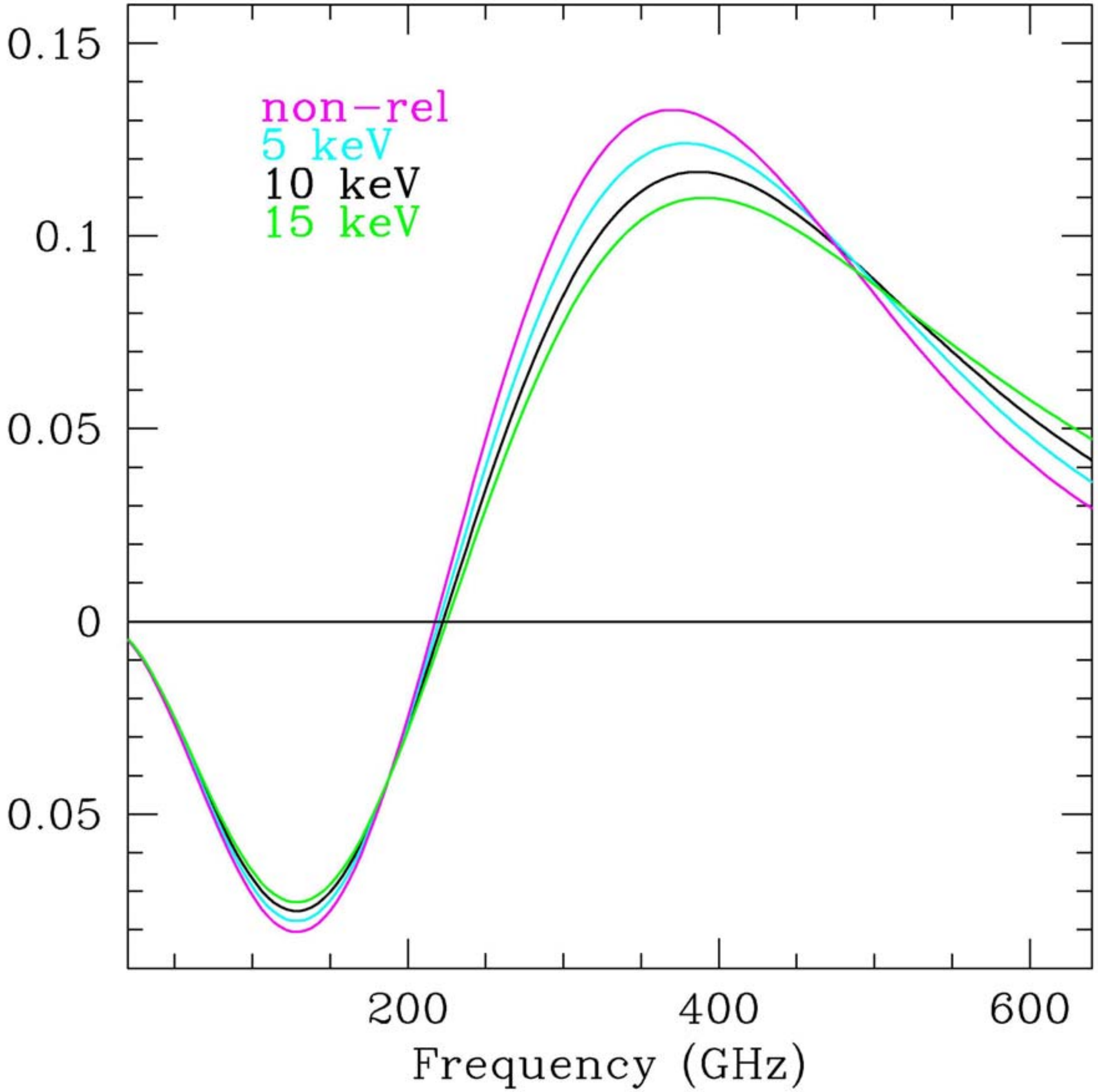


Benson et al 2003 (SuZIE II)

Relativistic Corrections to Thermal SZ Effect

uK imaging should allow 1 kev accuracy in

SZ temperature



Same order of magnitude as kinetic SZ effect

Peculiar Velocities (Kinetic SZ)

- Pure redshift, blueshift => thermal spectrum

$$\frac{\Delta T}{T} = \tau \left(\frac{\mathrm{v}}{c} \right)$$

Typical cluster signal: ~20 uK

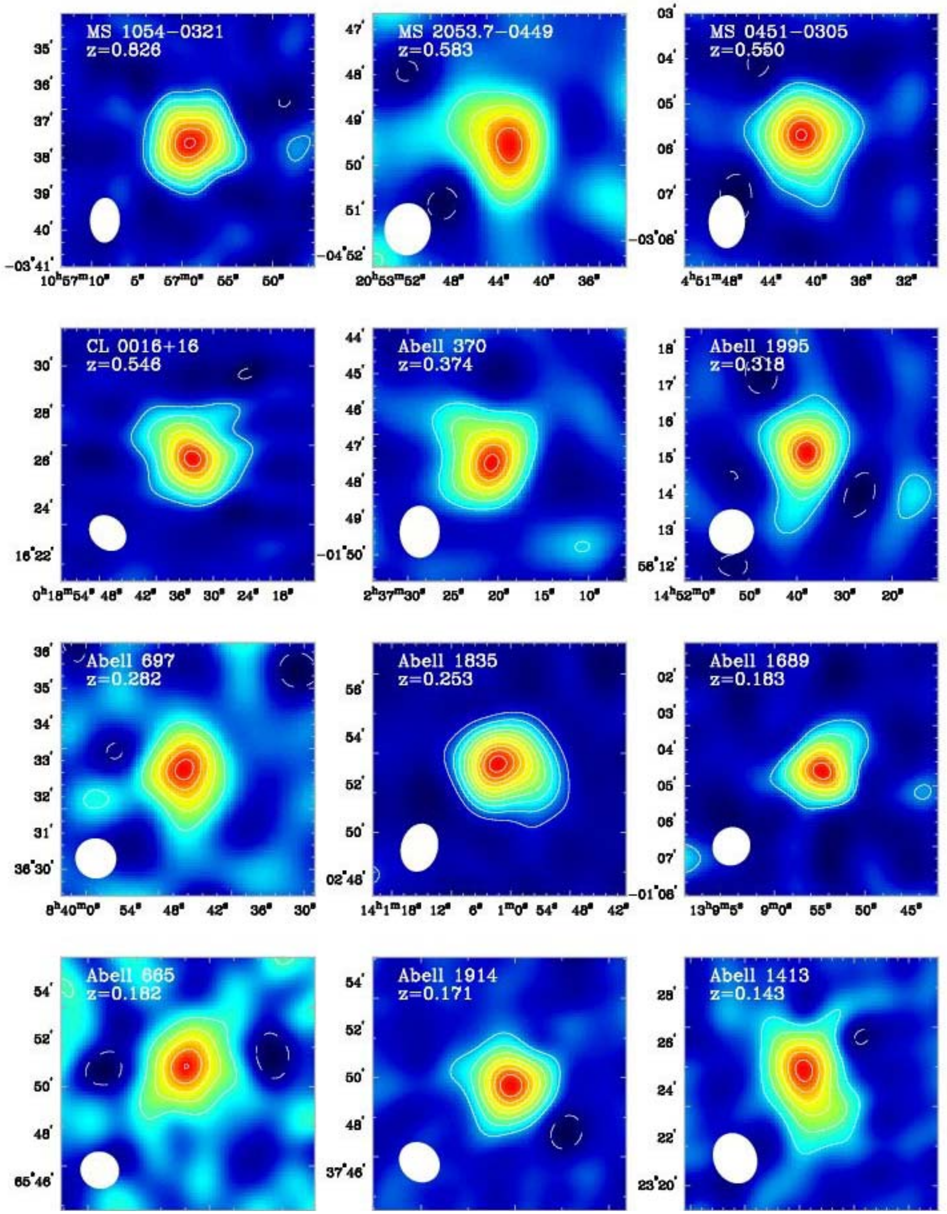
Kinetic SZ from large scale structure:
"Vishniac Effect'' (*expected signal ~1 uK*)

Astrophysical confusion:
•dusty submm-luminous galaxies
• Internal bulk flows (>100 km/s)

Z=0.83

Massive, X-ray selected clusters

Typical exposure ~40 hr

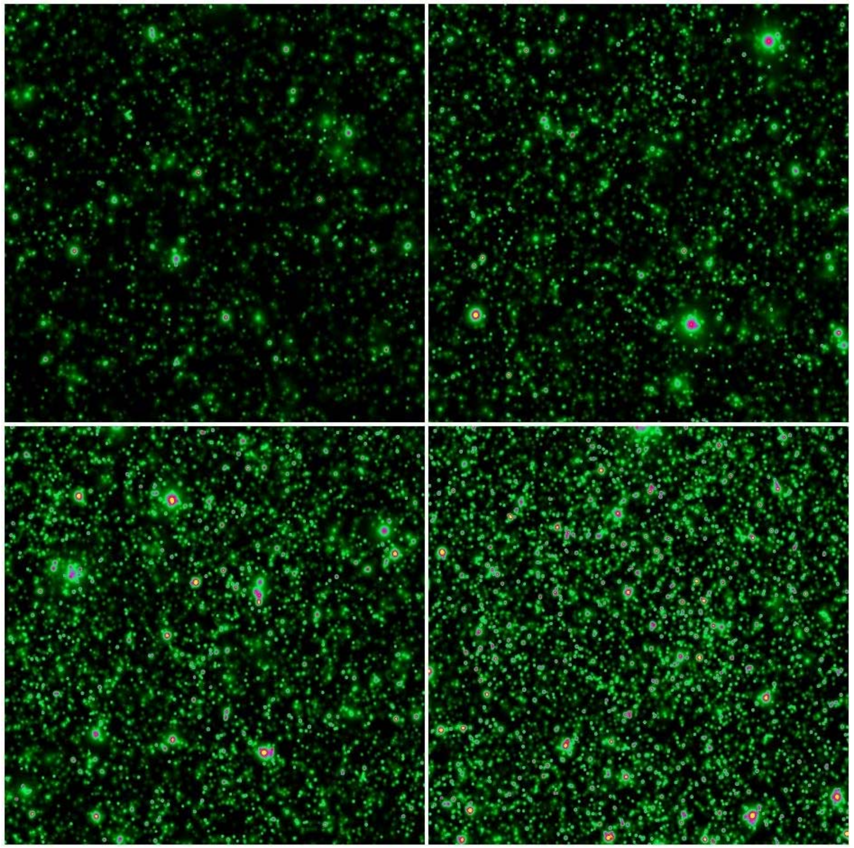


Z=0.14

Carlstrom & Joy SZ Imaging Project (30 GHz)

Cosmology with SZ surveys?

- Cluster counts very sensitive to cosmology (especially power spectrum amplitude and evolution)
- Cluster counts very sensitive to mass-observable mapping



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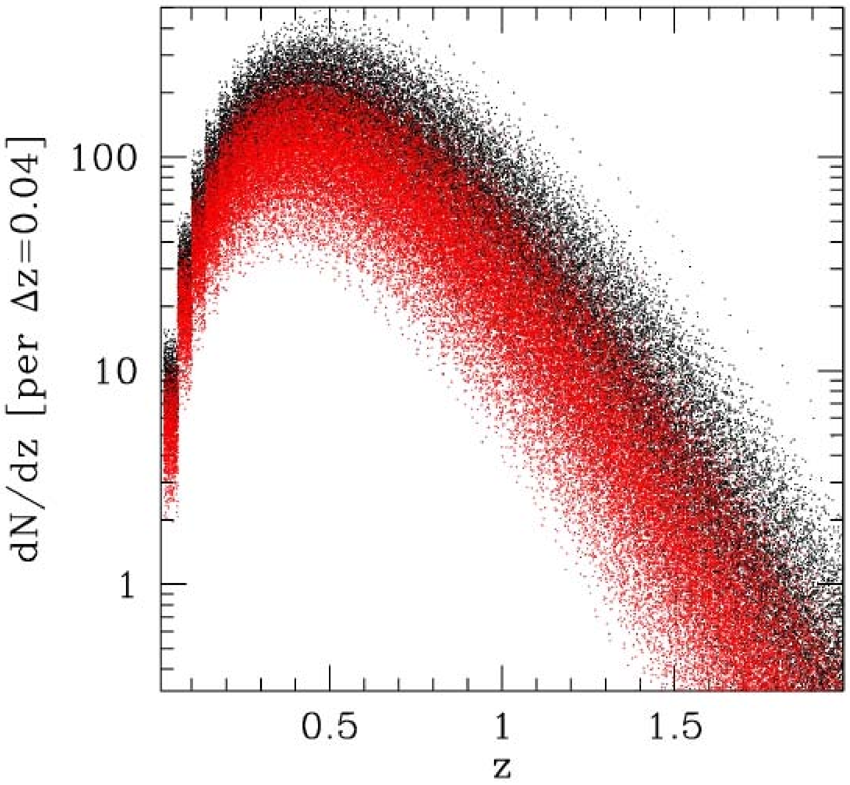


Upcoming/Ongoing Surveys

- Interferometric
  - N telescopes, 1 receiver each
  - Diameter D
  - Typical spacing B
  - "Beam" size: (λ/B)
  - FOV area: $(\lambda/D)^2$
  - Severe attenuation of diffuse emission beyond FOV
  - Great systematics control (many things removed in hardware!)

	AMI	SZA	AMIBA
Freq (GHz)	15	30 (90)	90
Band (GHz)	5	10	20
Tsys (K)	25	45	75
N (telescopes)	10	8	19
Diam (m)	3.7	3.5	1.2
λ/D (')	18	10	9.5
Sensitivity ("uK") 1 month, 3' beam, 1 sq deg	7	10	5 [20]

Very rough estimates

- Single dish
  - N detectors in focal plane
  - Diameter D
  - Beam size: (λ/D)
  - FOV area: $N*(\lambda/D)^2$
  - Atmosphere, ground, etc., have to be removed by hand

	ACT	SPT
Freq (GHz)	150, 220, 270	90, 150, 220
N (detectors)	2000	1000
Diam (m)	6	10
λ/D (')	1.2, 0.8, 0.6	1.2, 0.7, 0.5
Nominal goal (2 years?)	300 deg^2 2 uK	4000 deg^2 10 uK

Concerns for SZ surveys

- source characterization:

  - what are we seeing?

- mass characterization:

  - how does what we see relate to what we can calculate?

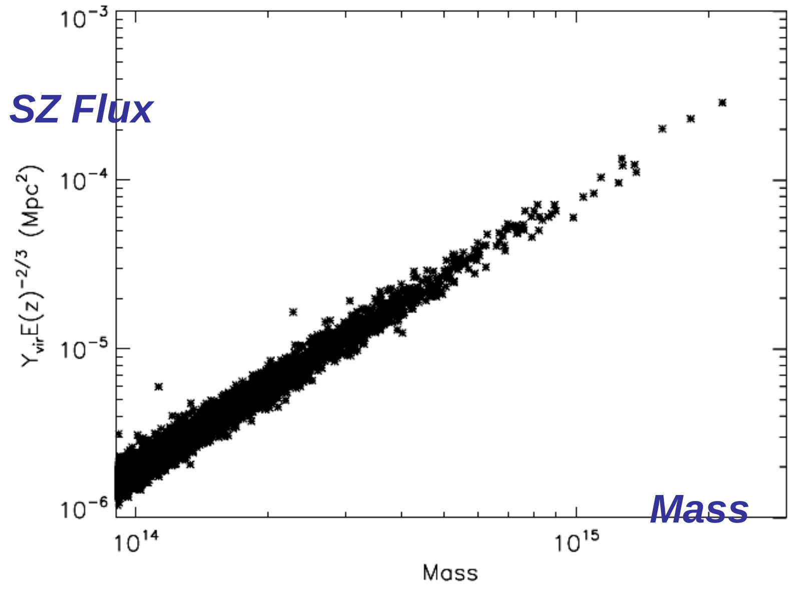
- contamination:

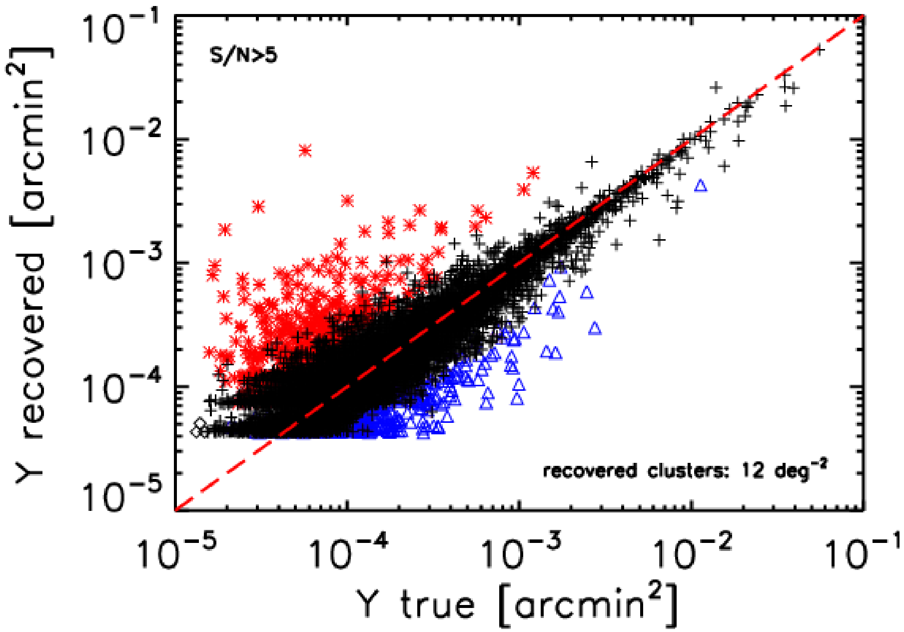
  - CMB, SZ confusion, point sources

Source Characterization

- In principle, SZ is a great mass estimator (Barbosa et al 96)
- Two problems
  - Projection effects
  - Recovering true flux from a noisy map

Hallman et al 2007



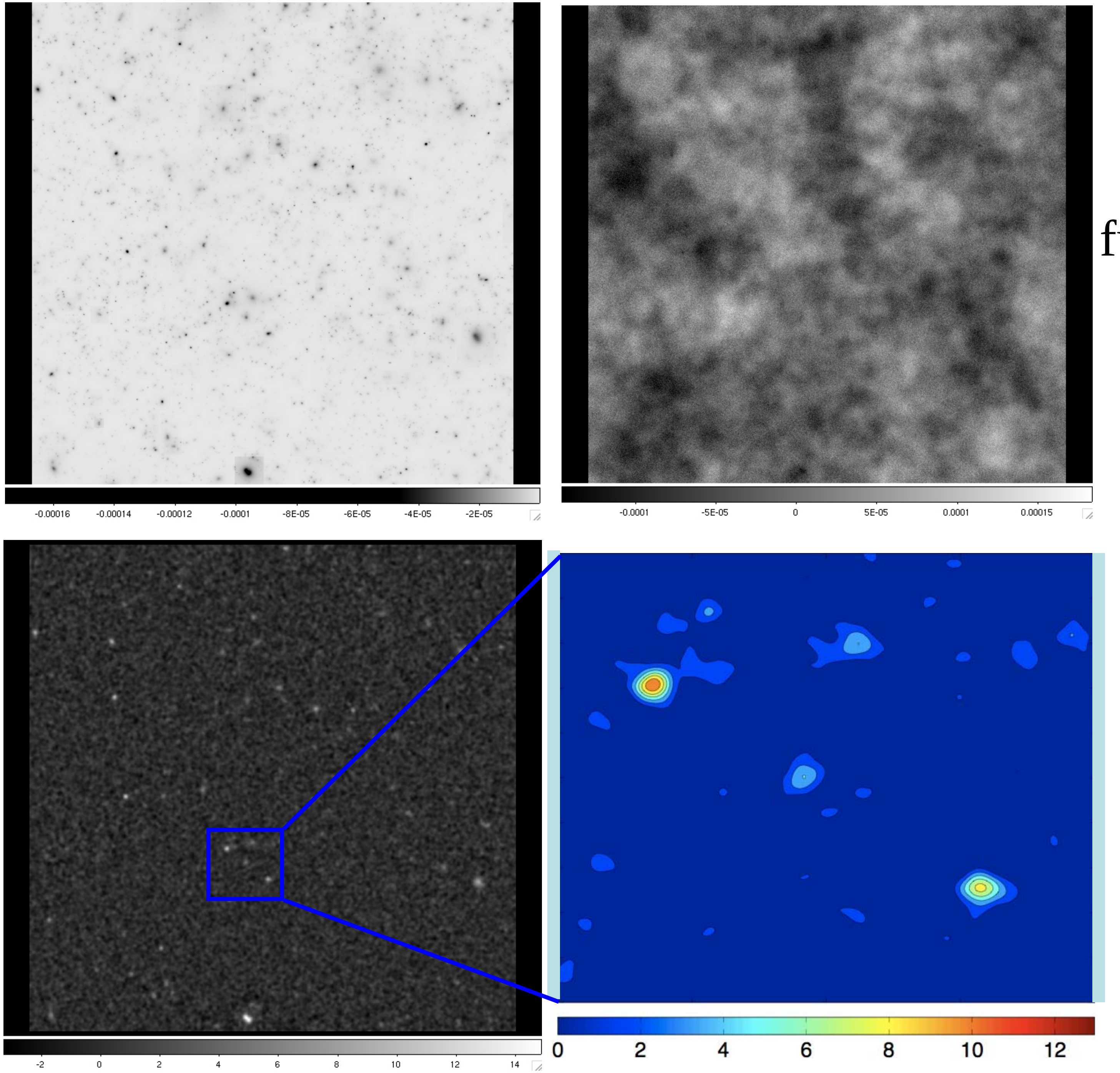


Melin et al 2006

SZ only

full map

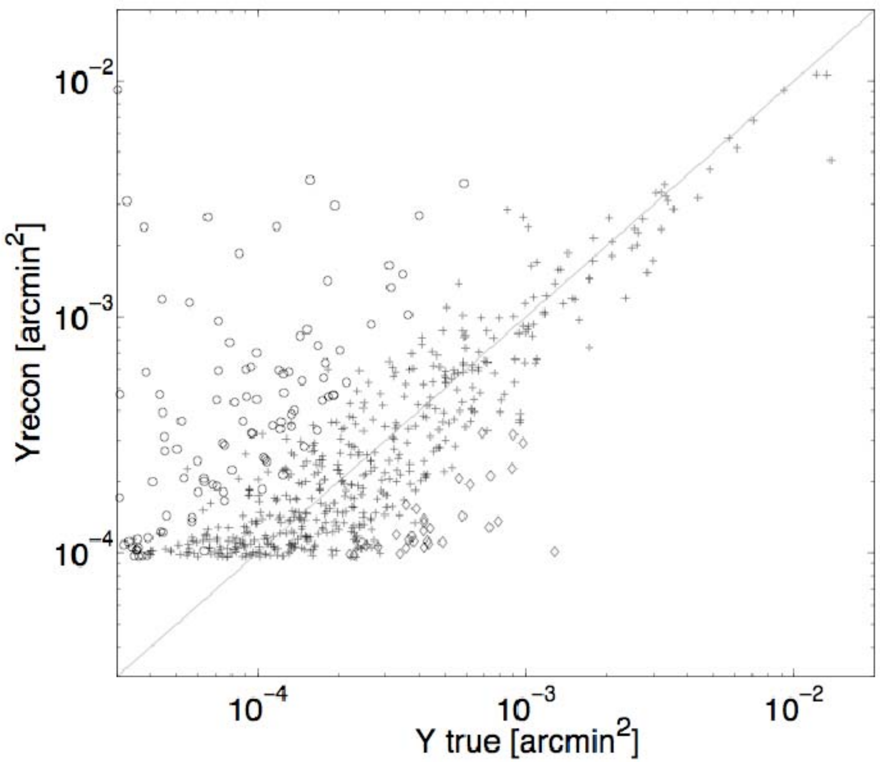
filtered
1 arcmin



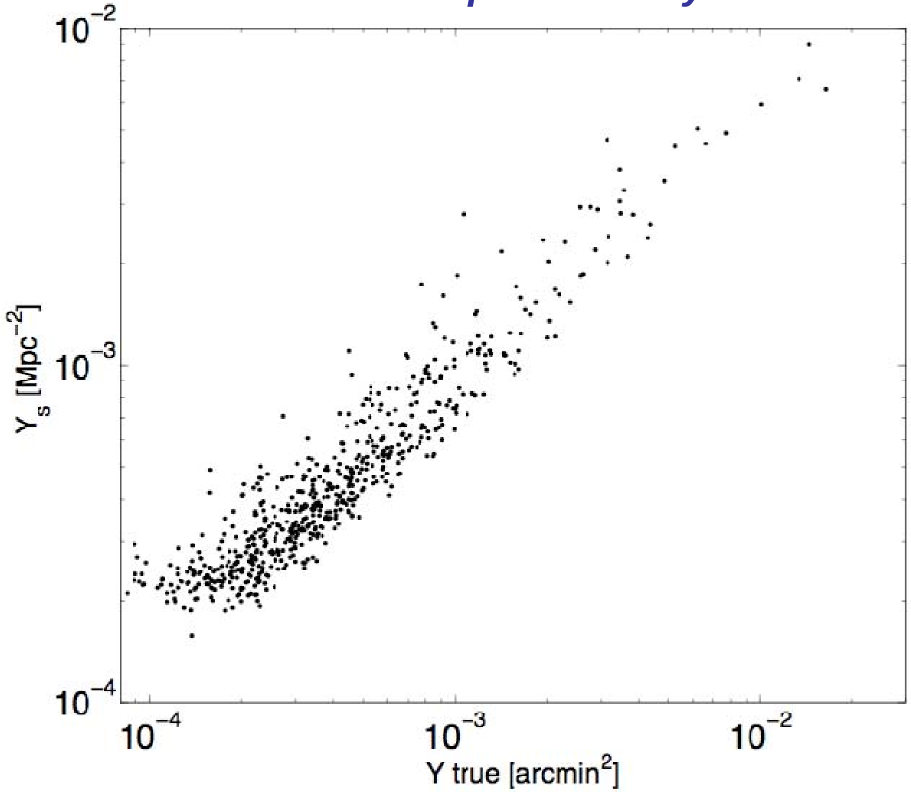
Laurie Shaw

A Tighter SZ Indicator

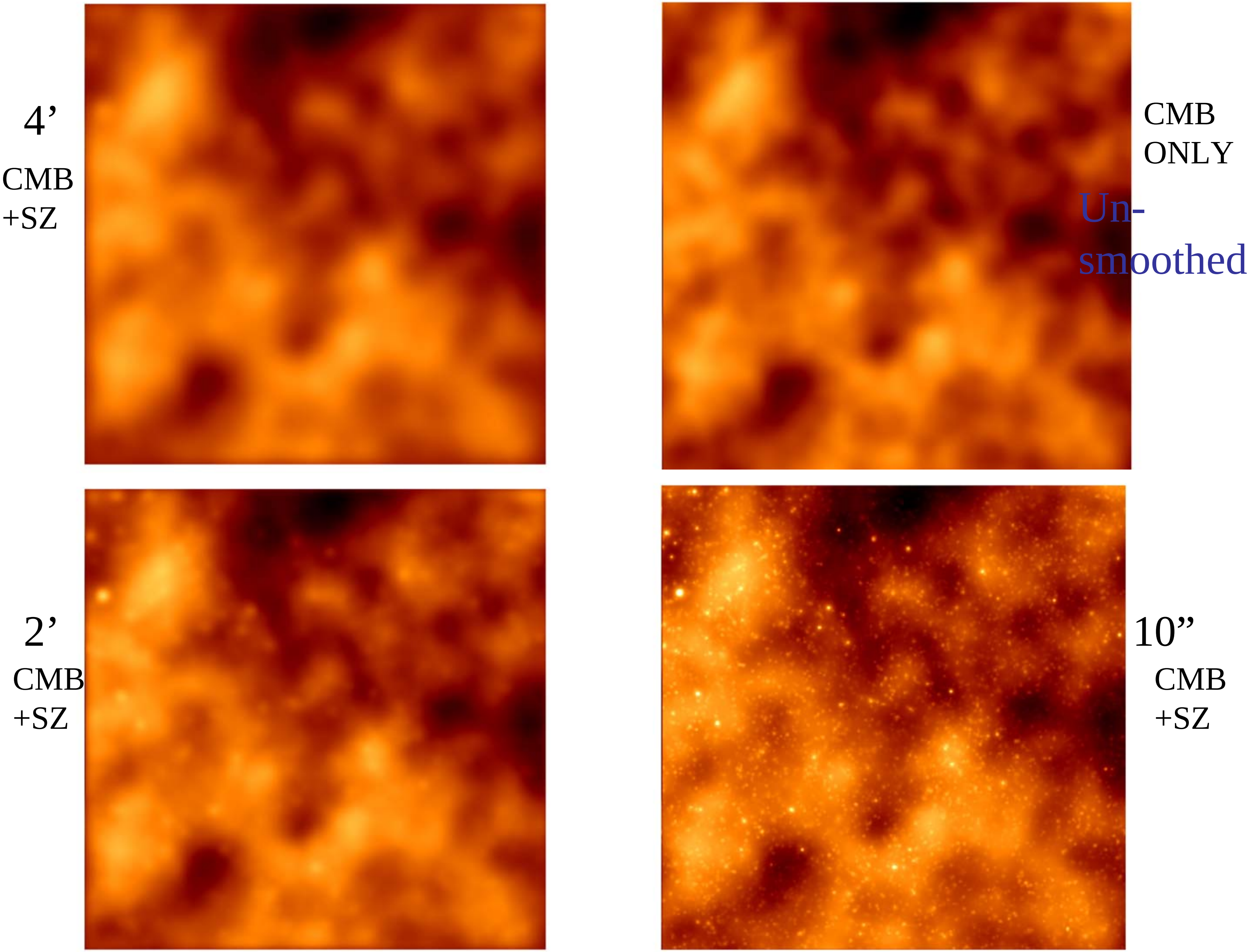
Reconstructed total flux from matched filter



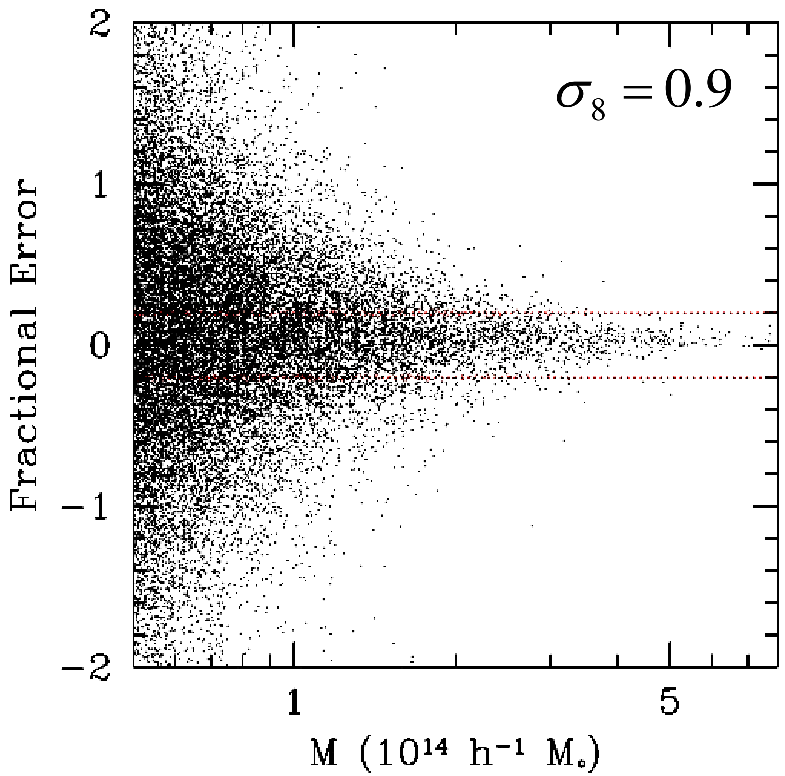
Matched filter output central y

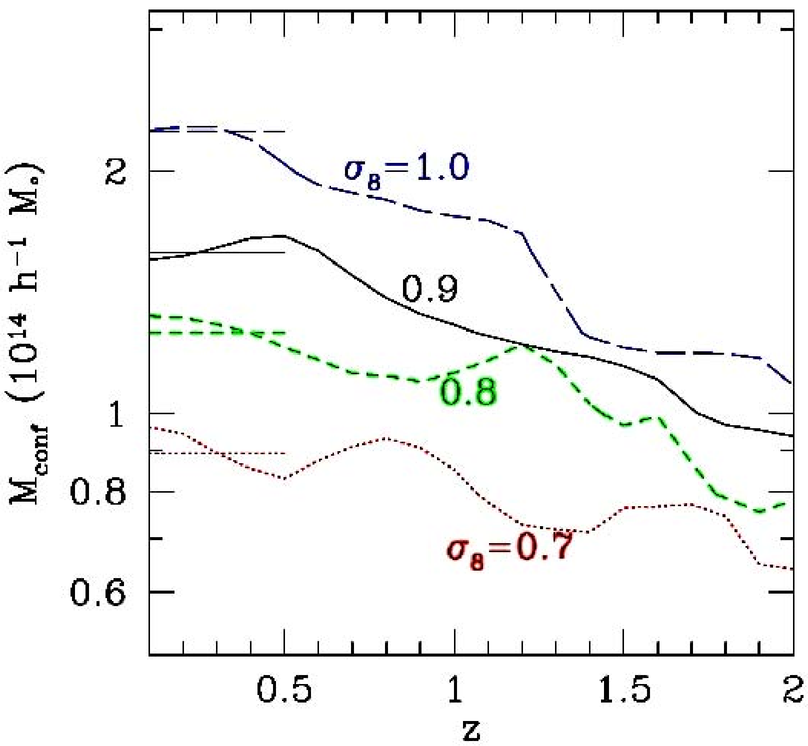


Laurie Shaw


4’
CMB
+SZ
CMB
ONLY
Un-
smoothed
2’
CMB
+SZ
10”
CMB
+SZ

SZ Confusion





(input-measured)/input for simulated filtered SZ maps

Mass at which rms error is 20%

Point Sources

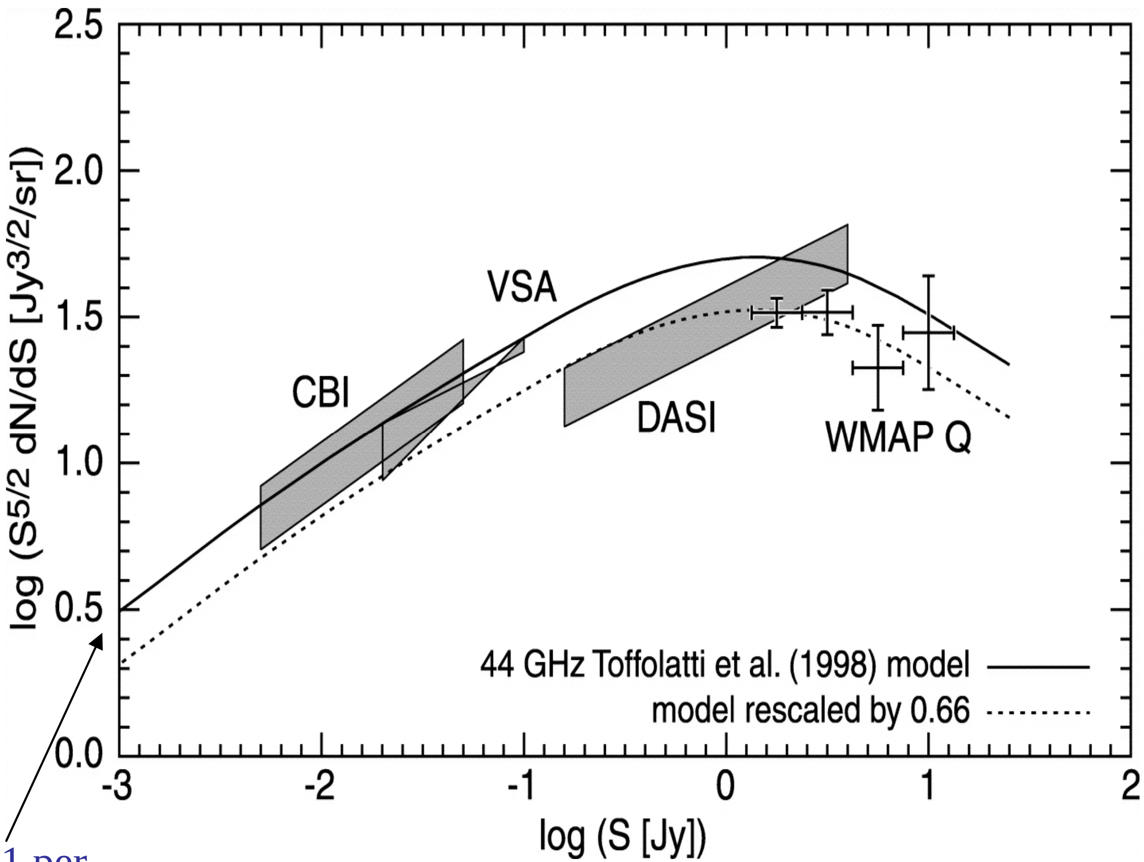
- Especially important for expts without pt src monitors (i.e., SZA, AMI fine)
- Radio Sources:
  - Random population irrelevant
  - Correlated sources: how many cluster galaxies host radio sources bright at higher frequencies?
    - How many radio sources in z~1 intermediate mass clusters?
    - What is a typical spectrum from radio to cm/mm?
- IR (submm) sources
  - Random population important for deep SZ images
  - Correlated sources:
    - Cluster sources - probably not a big deal, but….
    - Gravitational lensing: on average not a big deal, but…

Radio Galaxies

- random Poisson radio sources almost certainly not a problem at 150 GHz and above

- radio sources correlated with clusters, galaxies, etc. could be problematic for studies of secondaries

- Generally falling spectra in flux (flat => $1/\nu^2$ in CMB units)



~ 0.01 per square arcminute

Bennett et al (2003) [WMAP foregrounds paper]

Radio Source Spectra

[a public service announcement]

- non-trivial spectra (e.g., Herbig & Readhead 1992)
- Need more data at low fluxes and high frequencies (lots of data at 1.4 GHz)

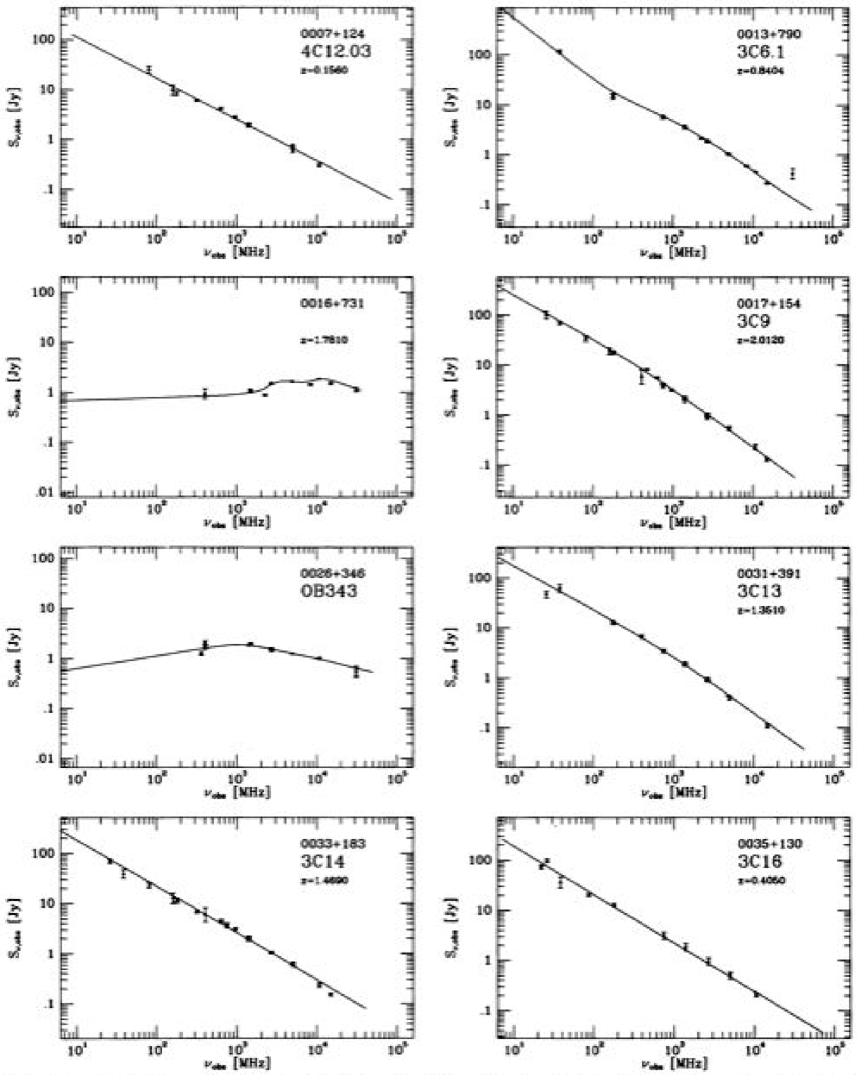


FIG. 1.—Observed radio spectra of the 256 objects in the combined LRL, PW, and PR samples. Both coordinates have the same scale in all panels so that spectra may be compared directly by eye. The points with error bars represent published flux density measurements, whereas the solid line depicts our weighted spline fits (defined in the range of the observed points), along with the extrapolations used in the calculation of the bolometric luminosities. Each panel is identified by the object's IAU name and its most commonly used other name, along with the redshift of the source if known.

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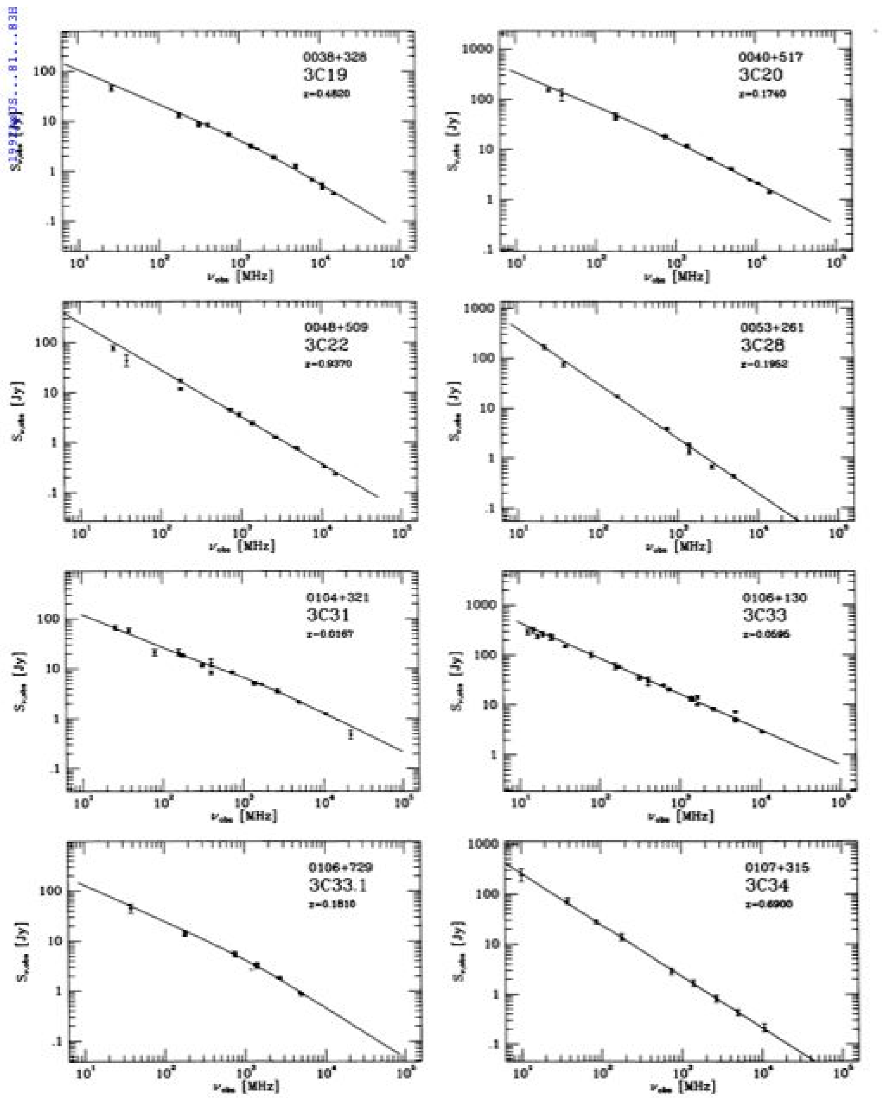

FIG. 1—*Continued*

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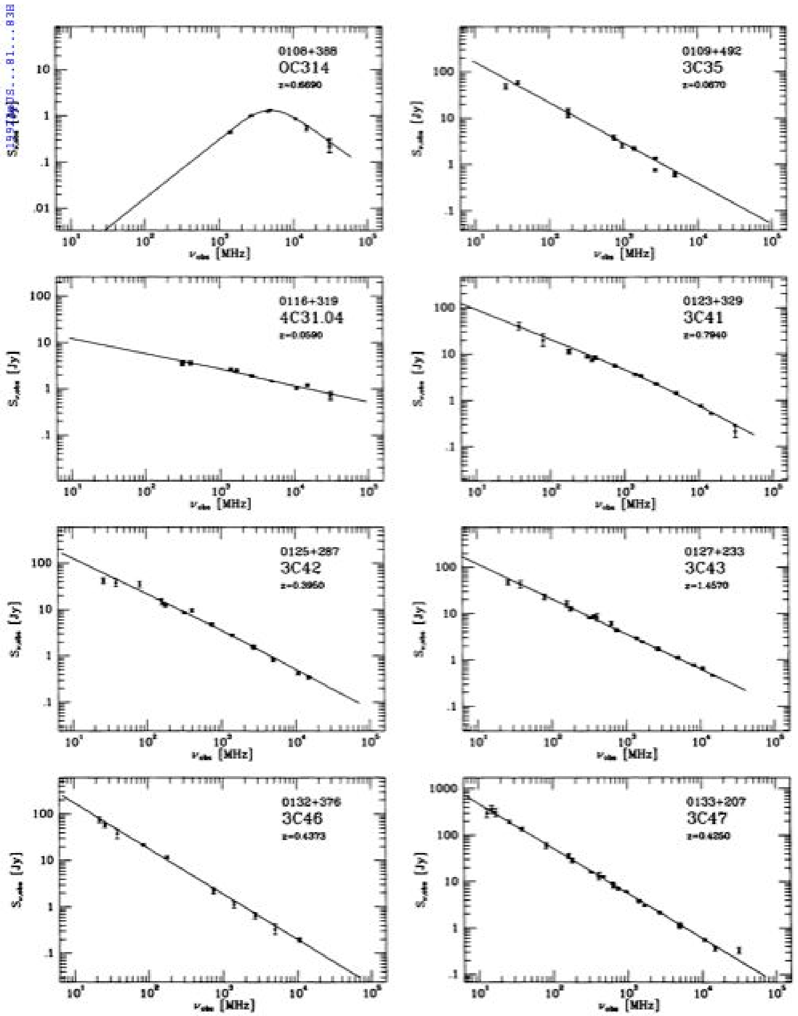

FIG. 1—*Continued*

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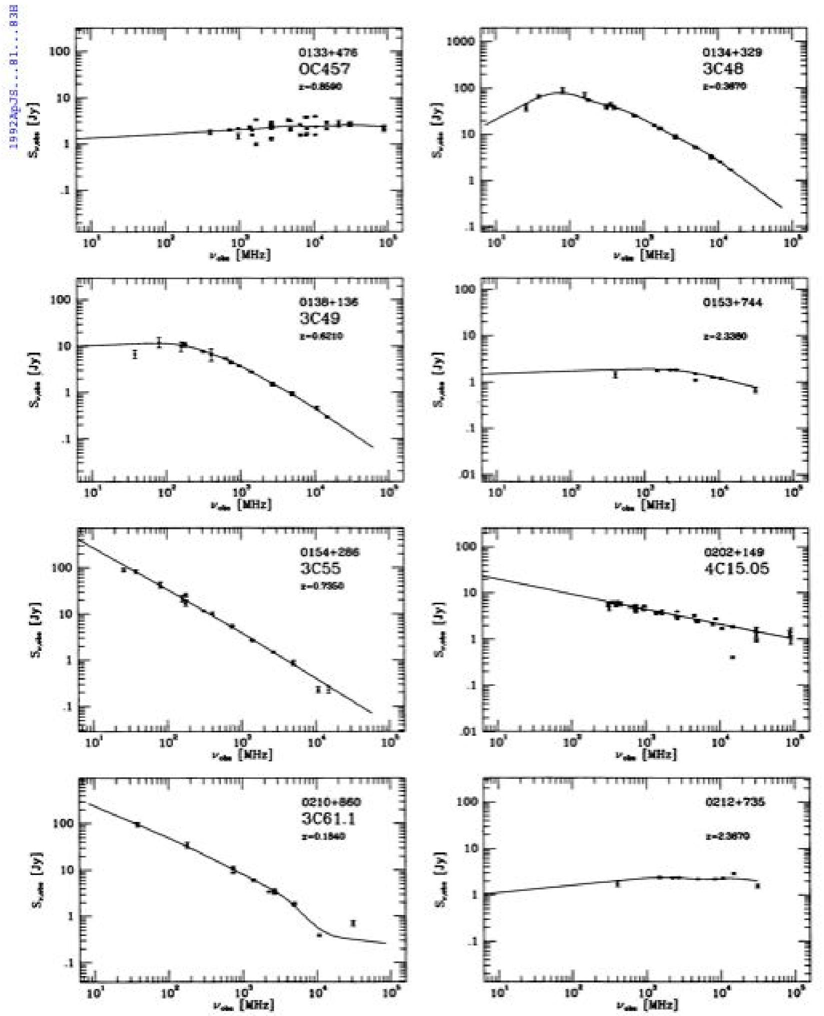

FIG. 1—*Continued*

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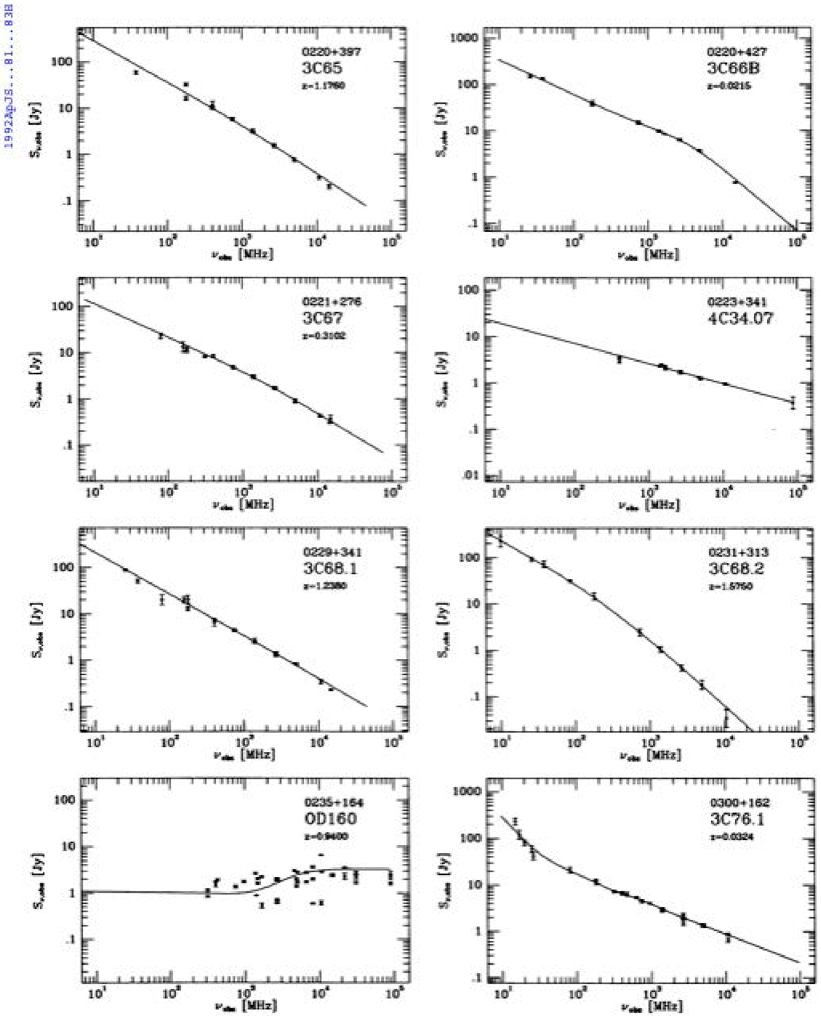

FIG. 1—*Continued*

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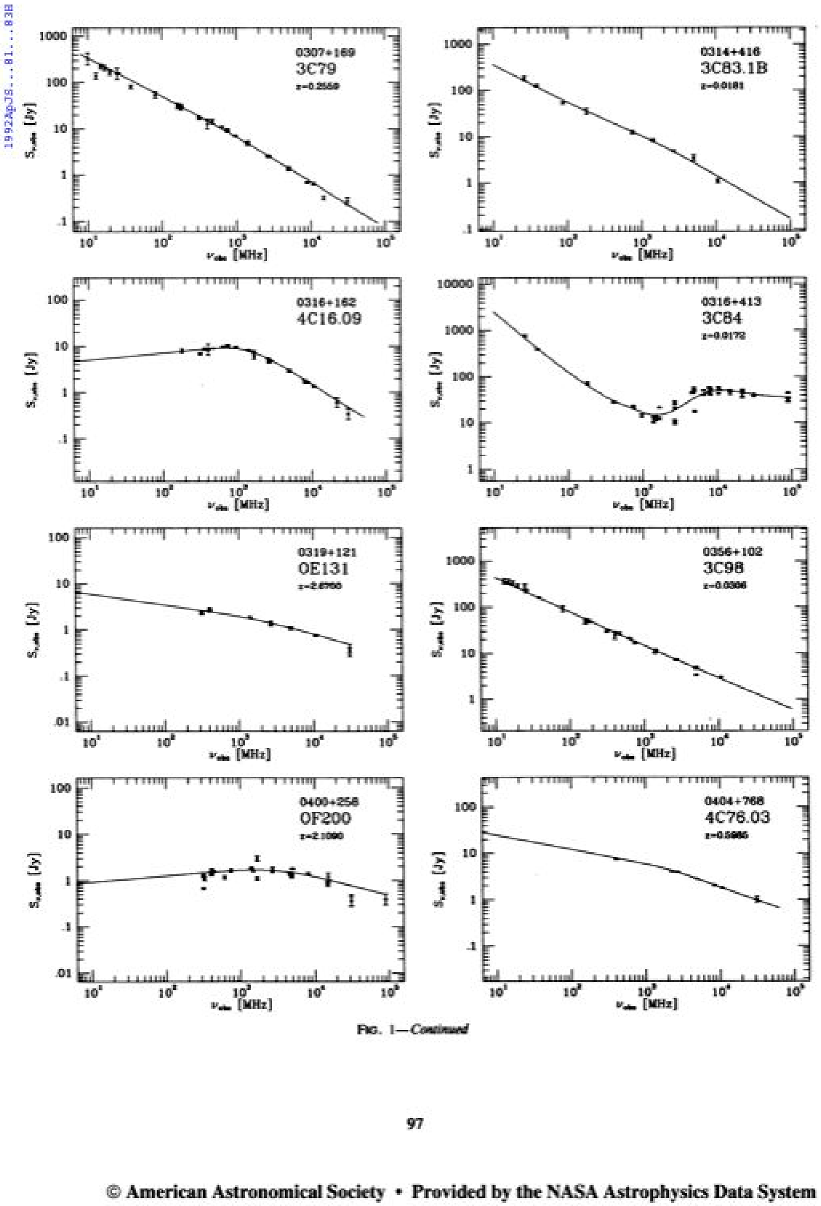

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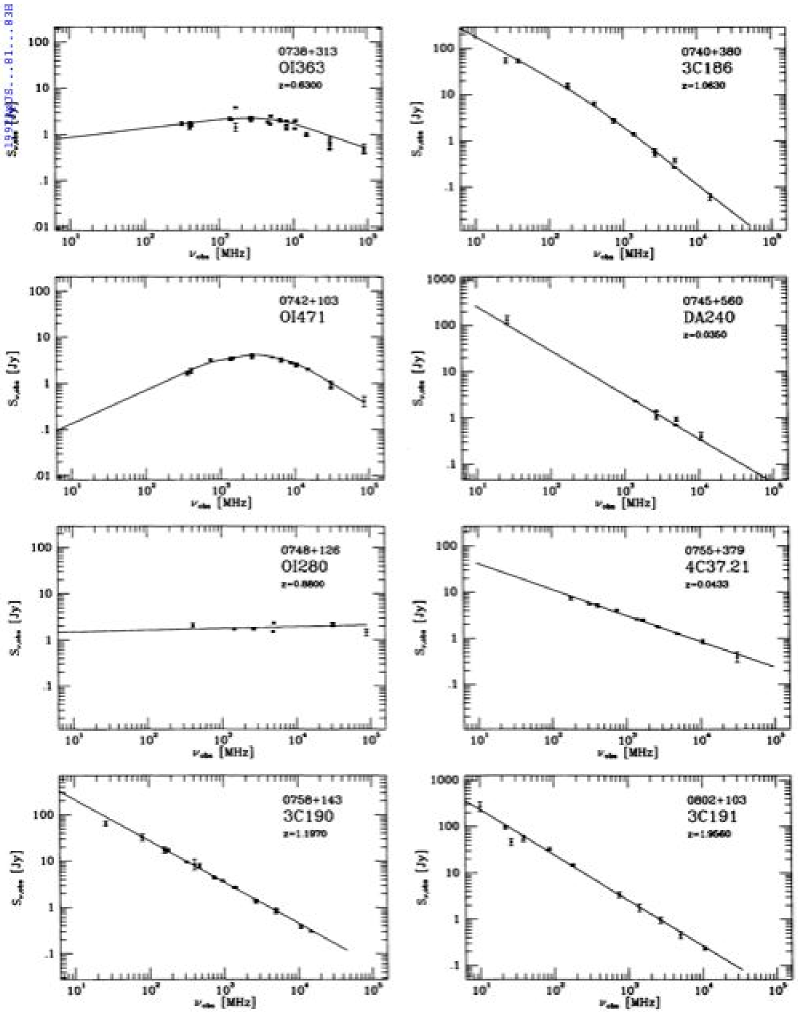

FIG. 1—*Continued*

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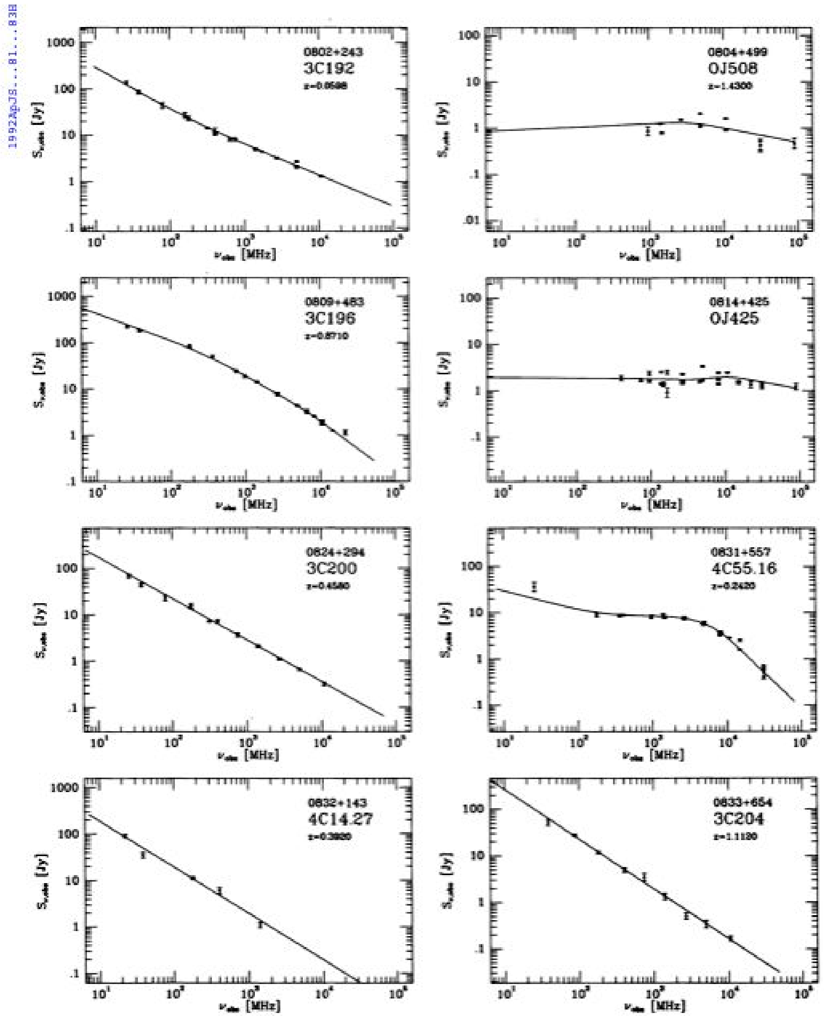

FIG. 1—*Continued*

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Radio Source Spectra

[a public service announcement]

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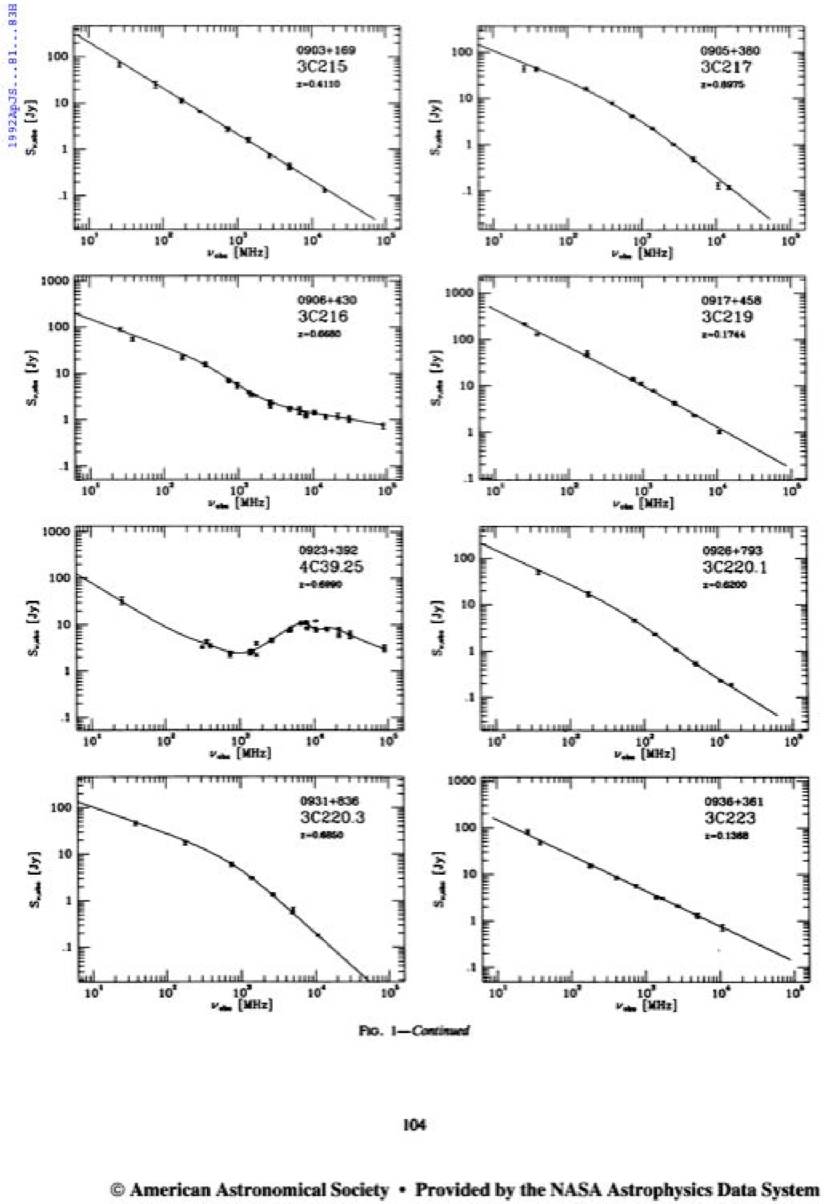
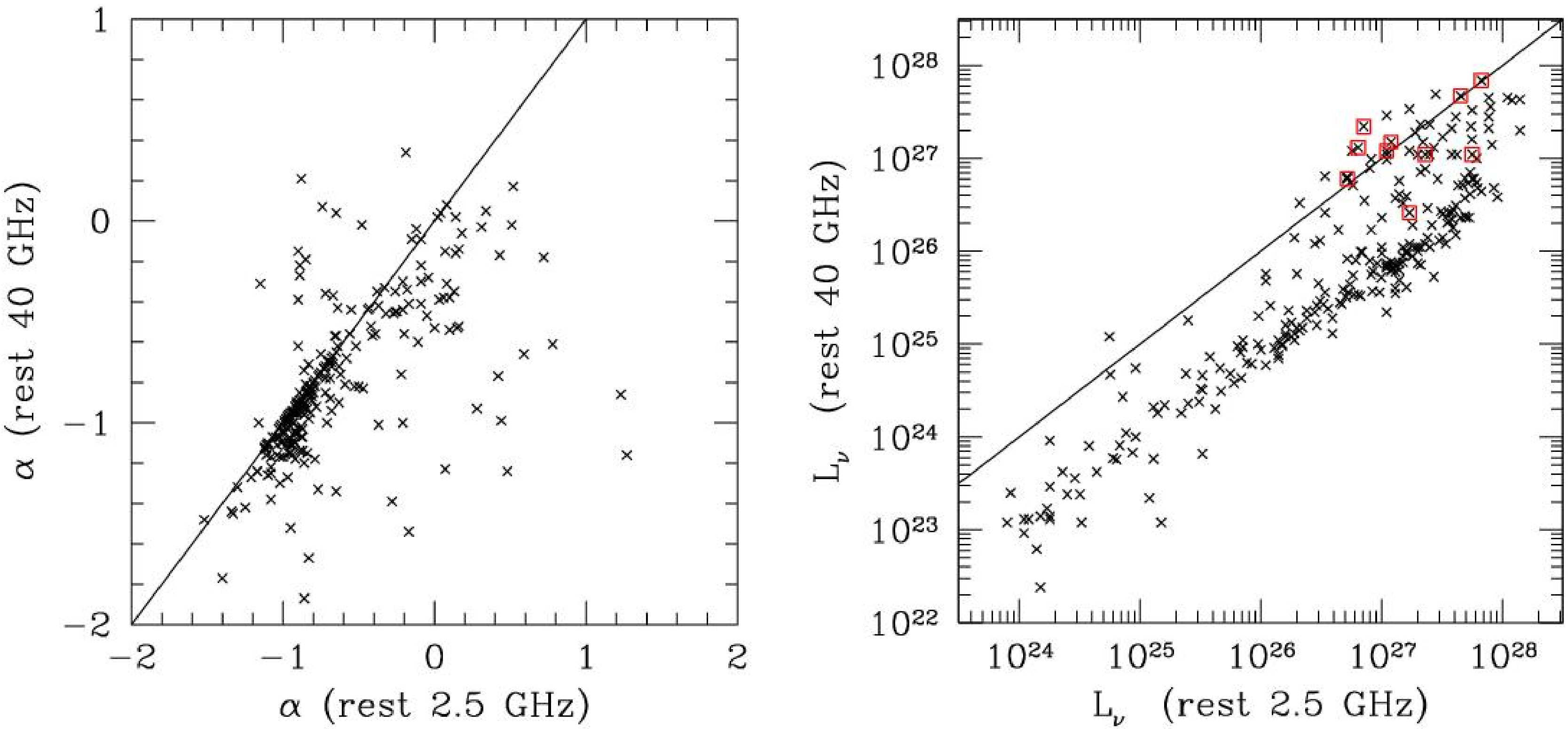


Extrapolating Radio Sources



Red squares: flat or rising spectra at 40 GHz

Data from Herbig & Readhead 1992

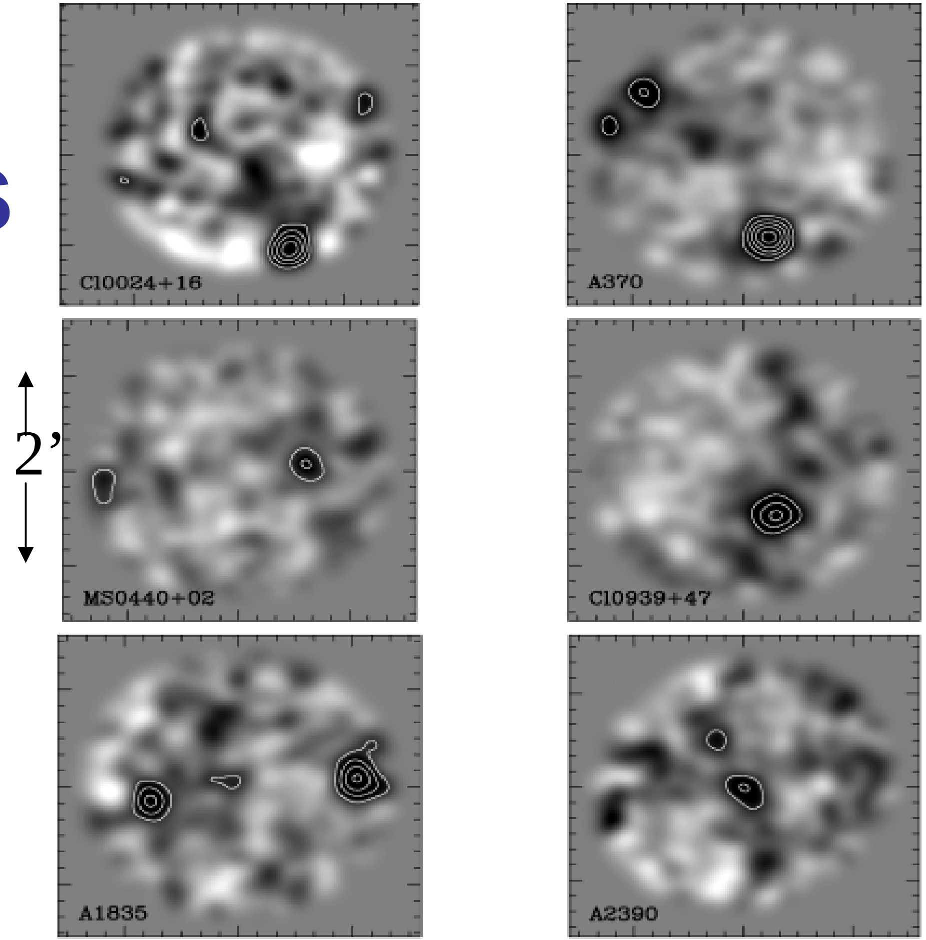
Bottom line: a few % of radio sources should be as bright at high frequencies as at 1.4 GHz (in flux, not temperature)

Dusty Galaxies

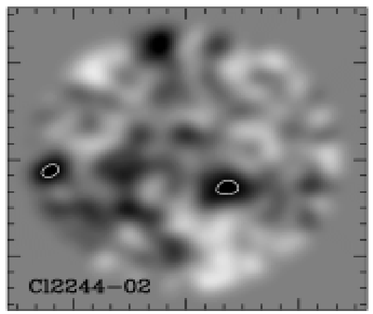
- <u>1 mJy at 150 GHz in a 1' beam => ~ 30 uK</u>
- ***Roughly one 0.2 mJy source per arcm²***

  (based on Scuba counts; Borys et al extrapolated to 150 GHz)
- *How well can these be subtracted?*
- ***Not a problem for ALMA***

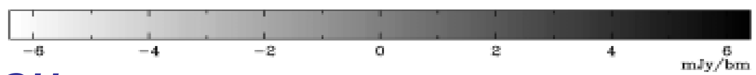
(30 σ in 60 seconds)



Several mJy fluxes at 350 GHz



Smail et al (2002)

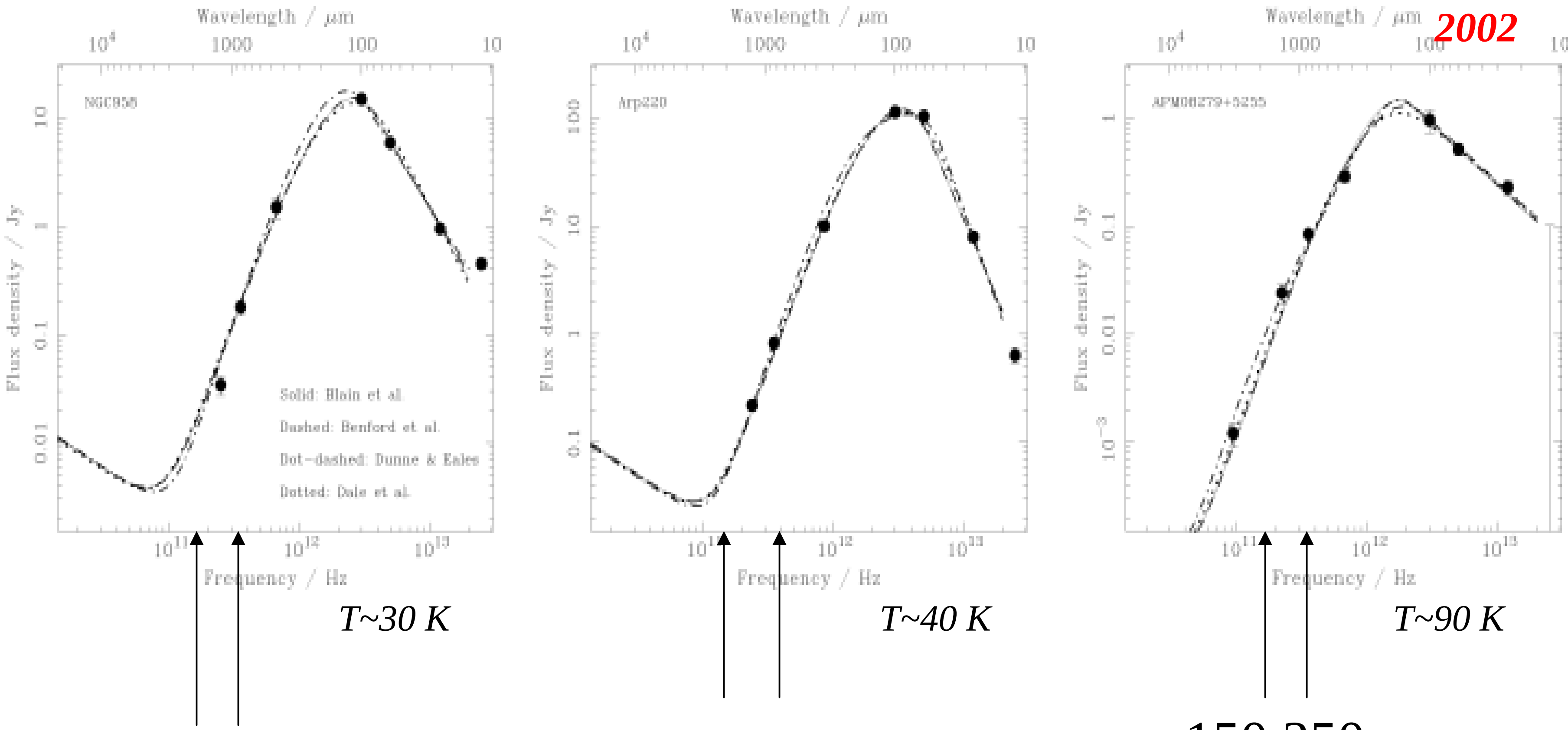


IR point sources:

2e14 mass clusters at 150 GHz <=> 1e15 mass at 350 GHz

Spectral Homogeneity?

z = 0.02 *z = 0.02* *z = 3.8* ***Blain et al 2002***



150 350 GHz

150 350 GHz

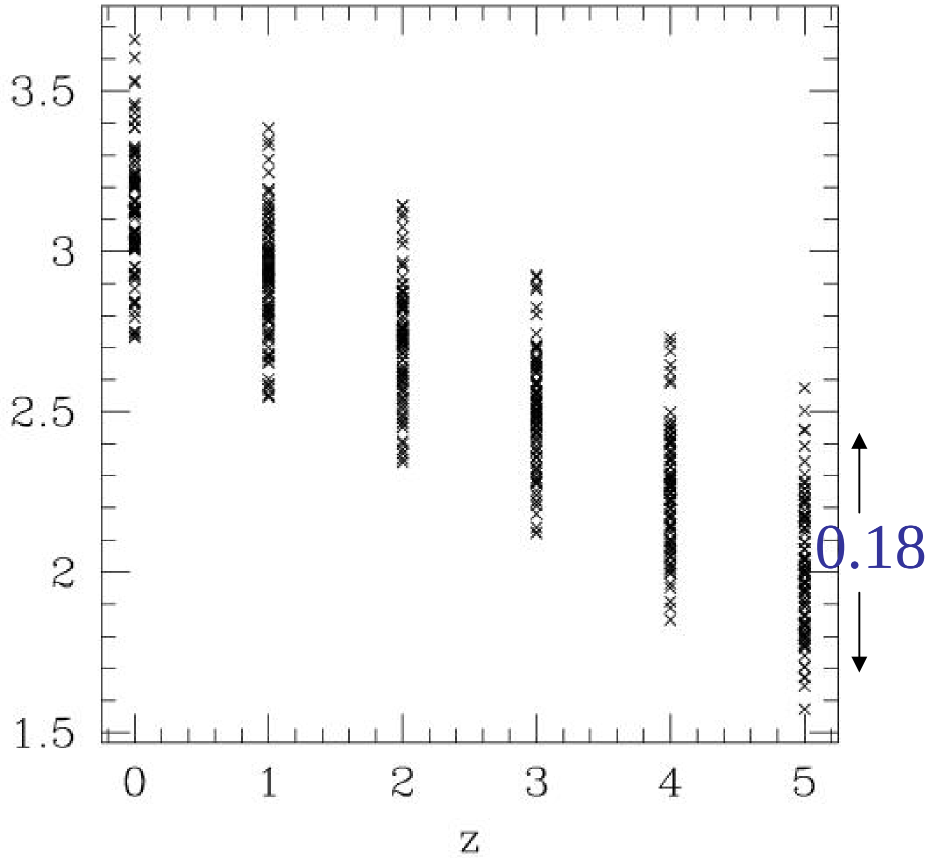
150 350 GHz

What are Local Galaxies Like?

- use local sample of luminous dusty galaxies (Dunne et al 2000)
- calculate 350/150 GHz spectral index for same sources at a variety of redshifts

$$S(Jy) = S_o \nu^{\alpha}$$

r.m.s. ~ 0.4 (over all z)



Warnings: a) this is based on old data

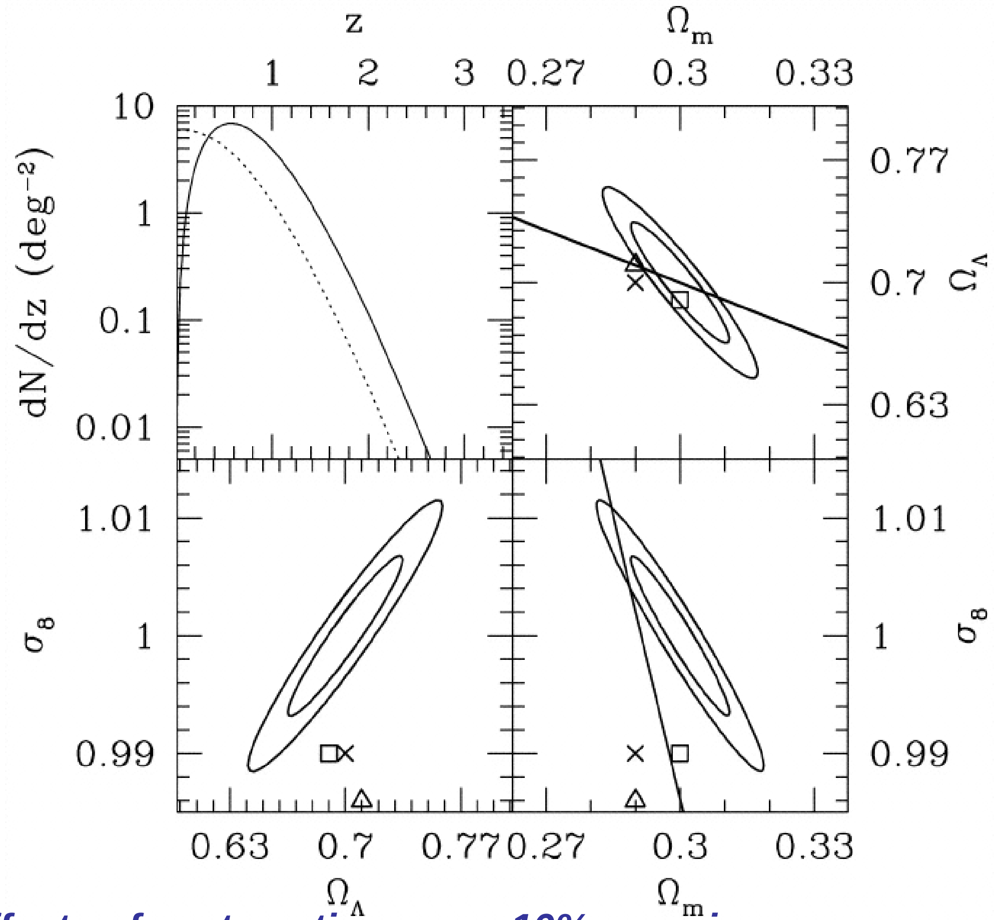
b) these data actually suck for this purpose

Parallel Observations?

- ***Herschel? (thanks to Ivan Valtchanov)***
    - Spire: 250(18”), 250(25”), 500(36”) um
    - large maps rms~10-20 mJy at 500 um (600 GHz)
    - => ~0.2-0.3 mJy at 150 GHz (in 36” beam)
    - SPT sources will be identified, for sure!
    - ATLAS has 2 SGP fields (total 295 deg^2) overlap with SPT
- ***ALMA?***
    - 1 minute snapshot sufficient in sensitivity
    - Small field of view (20” at 1mm) => mosaics
    - 1-2 months per square degree of survey
    - OR: 1-2 hours per cluster pointed follow-up

Mass Calibration

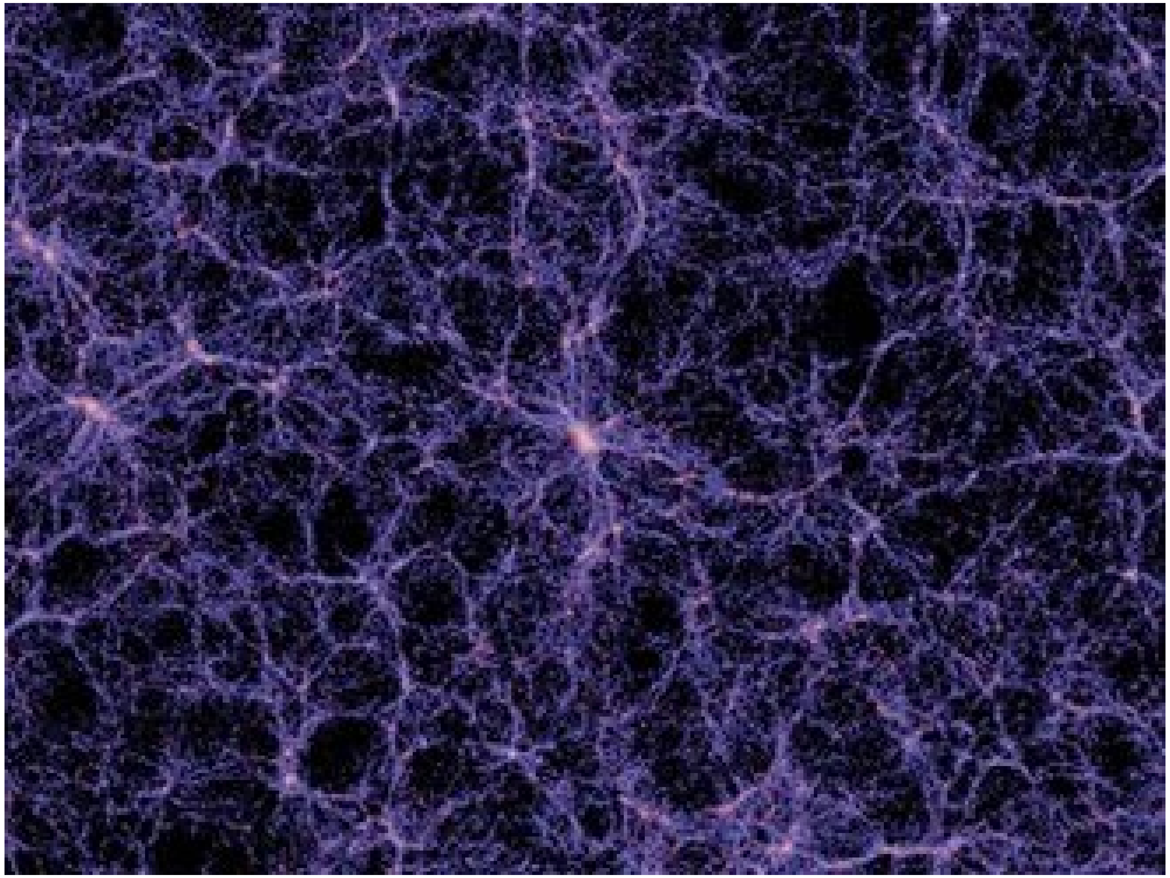
- Masses must be understood to better than 5% to match statistical errors
- Two options:
  - Internally solve for masses ("self-calibration")
    - Shape of mass function
    - clustering
  - Measure masses
    - Weak lensing or X-ray
    - Method must be unbiased to z~1 to few % level to be useful



Effects of systematic errors: 10% error in mass function (tilt, offset) or 5% error in limiting mass

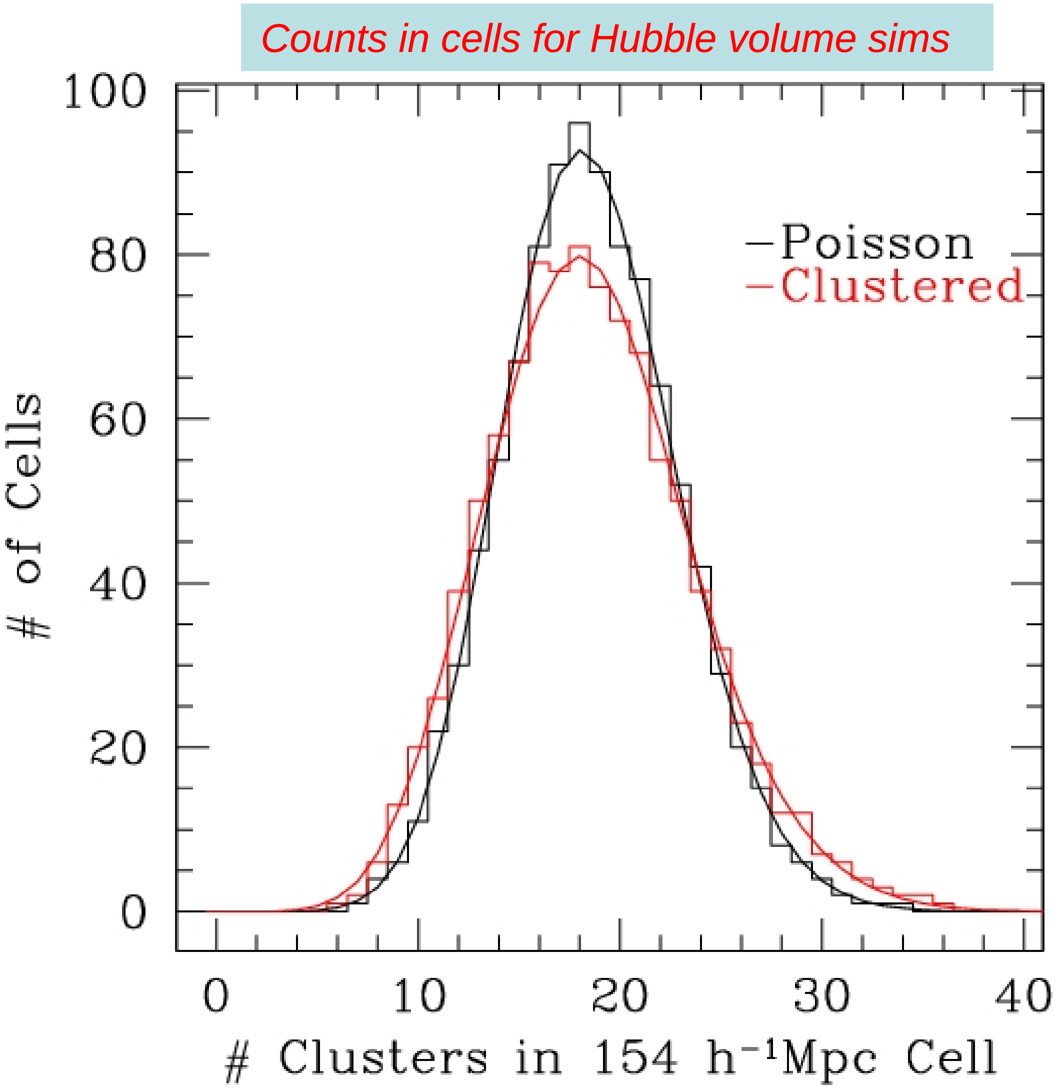
Holder, Haiman, Mohr

Clusters are clustered



Clusters are clustered

- Counts in cells can be calculated for a given cell size and set of cosmological parameters
- Bias is a function of mass: bigger things more clustered
- just like other objects: can estimate mass from clustering properties



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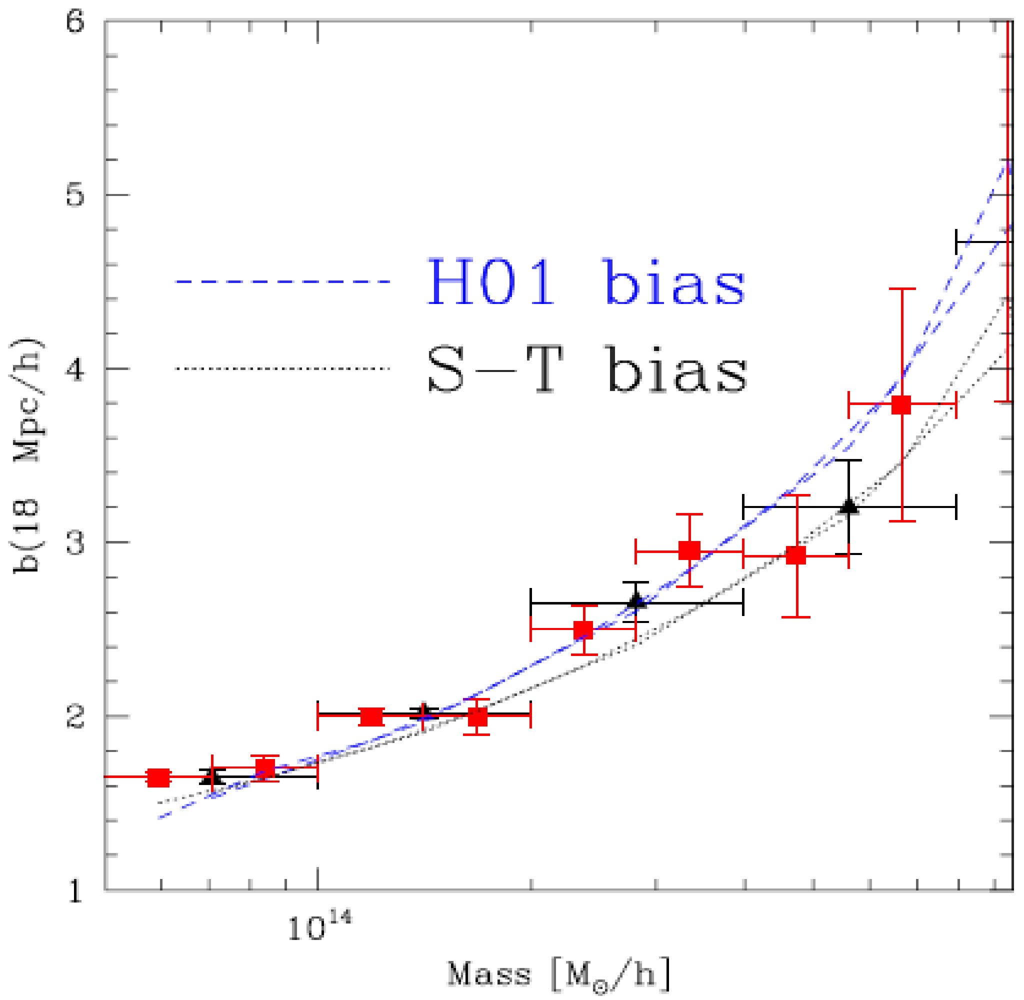
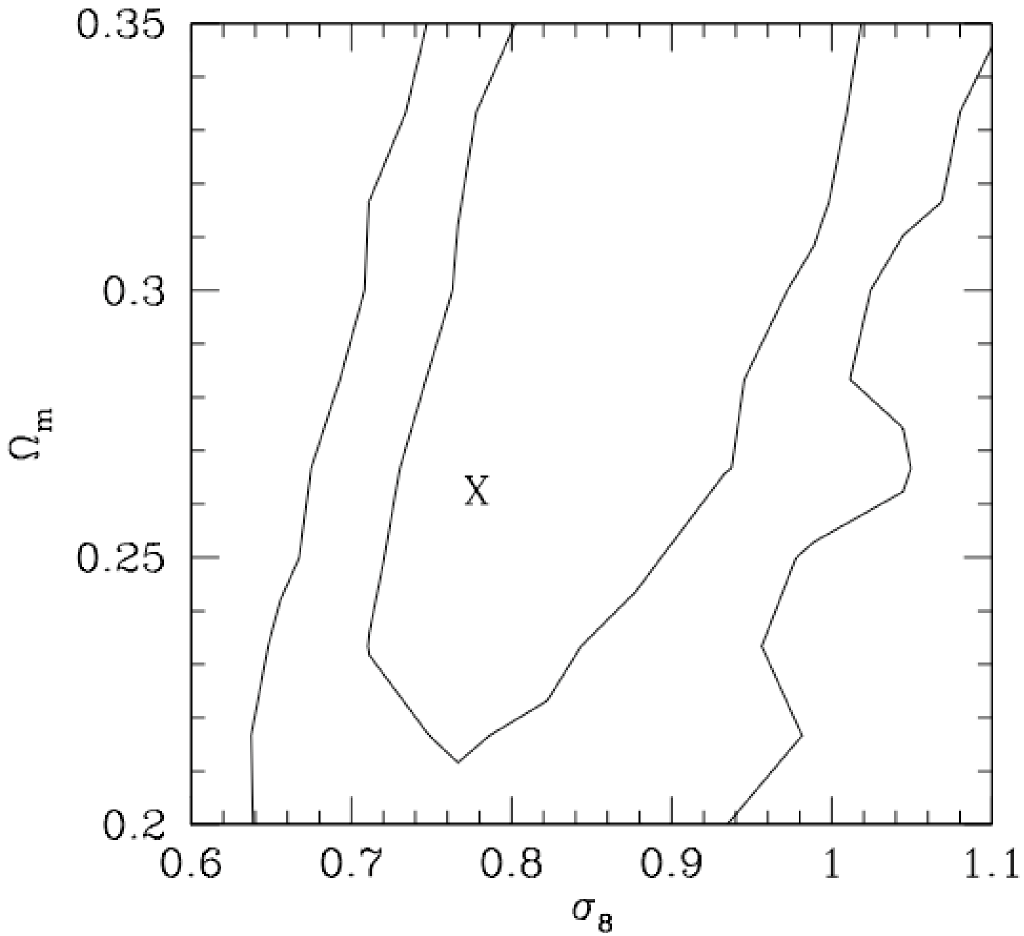


Wetzel et al. (2006)

SELF-CALIBRATION?

- ~400 sq deg cluster survey
- SZ+CMB+noise sky
- SPT-like (18 uK noise), 5 sigma detections
- marginalized over cluster scaling relations
(both M scaling and z scaling)
- No clustering information

Simulated SZ survey



SZ simulations by Laurie Shaw:

gas model painted onto large N-body simulation

Directed Conclusions

- Uniform selection function over large area is great for cluster surveys, well-matched to optical, lensing, SZ cluster surveys
- 200 deg2 (10 ks) vs 50 deg2 (40 ks)?
  - Probably 10 ks is fine for most SZ clusters (but….)
- One or two areas?
  - Only benefit of 1 area is for clustering studies which could be useful for understanding mass limits
- Follow-up needs:
  - optical photo-z (no need for spectroscopic z)
  - Weak lensing
  - High resolution submm, mm