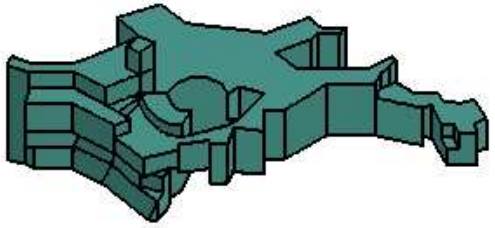
Optimised detection of SZ-clusters with PLANCK

workshop "SZ-effect and ALMA"
Institut d'Astrophysique Spatiale, Orsay

Björn Malte Schäfer (MPA)

spirou@mpa-garching.mpg.de

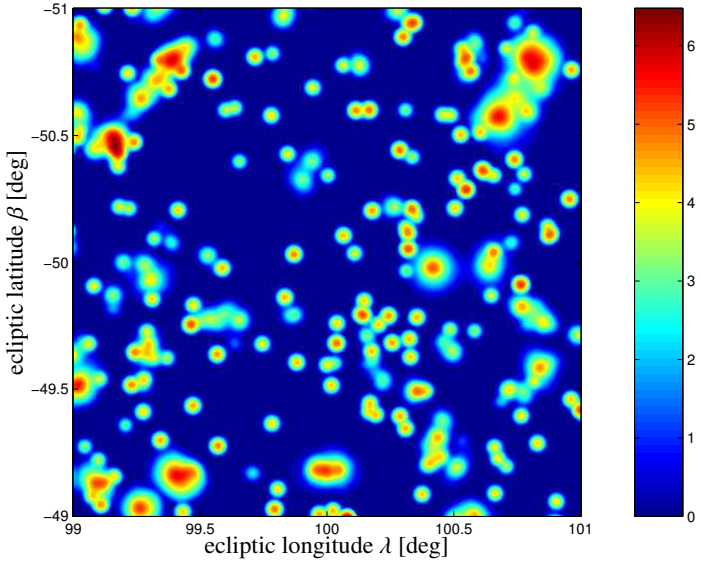


outline: SZ-clusters with PLANCK

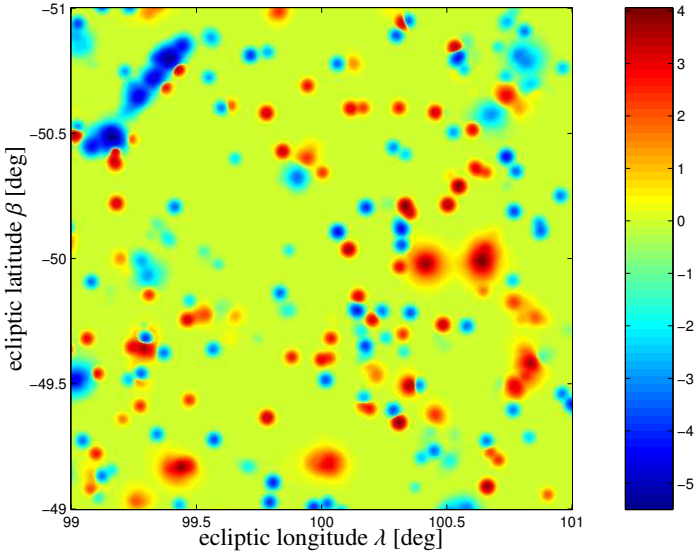
- try to cover every aspect of SZ-observations
- SZ-physics: hydrodynamical simulations of clusters
  deviation from scaling-laws, asymmetry, non-isothermality
- include (Galactic) foregrounds:
  synchrotron, dust, free-free, carbon monoxide, infra-red emission of planets and asteroids
- SZ-detection with PLANCK
  non-uniform detector noise, scanning, beams
- amplification and extraction of the weak SZ signal
  matched and scale-adaptive filtering, multifrequency observations, spherical geometry

thanks to: M. Bartelmann, C. Pfrommer, M. Reinecke, R. Hell

thermal and kinetic SZ-maps



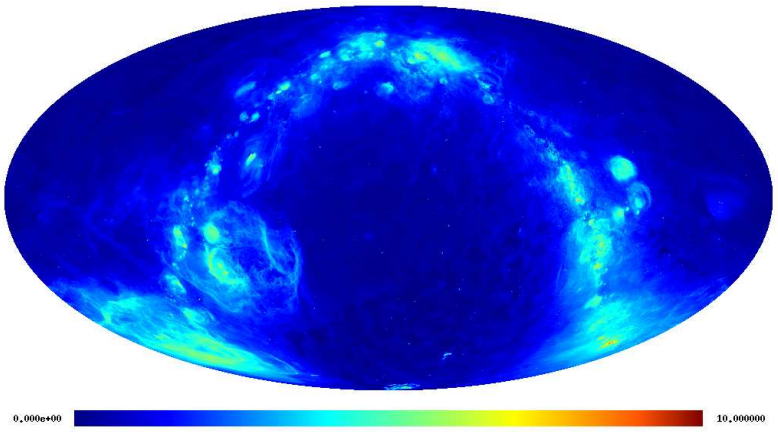
thermal SZ



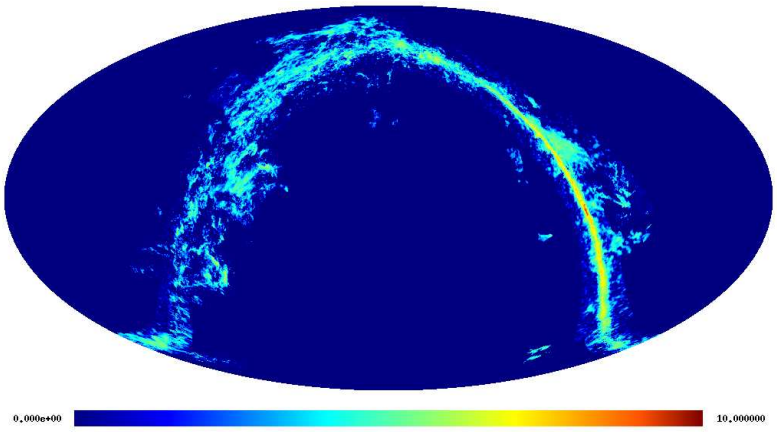
kinetic SZ

- complex substructure, orbiting clusters
- 50 clusters per square degree
- halo-halo correlation, (evolving) mass distribution
- velocities correspond to densities
- deviation from idealised scaling relations

Galactic foregrounds



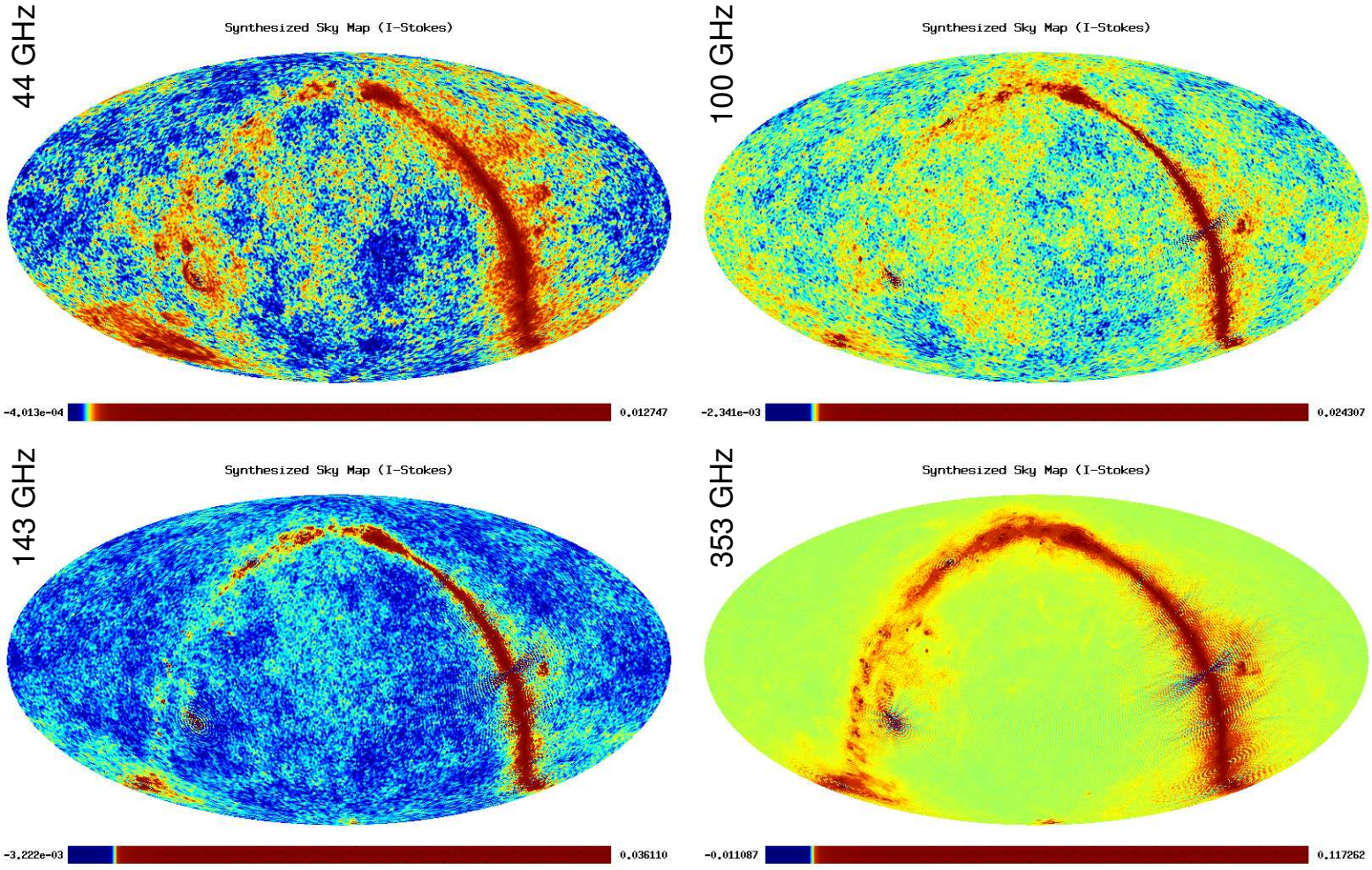
free-free



carbon monoxide

- Galactic foregrounds: dust and synchrotron
- new foregrounds: Galactic free-free and carbon monoxide
- infra-red emission from (moving) planets and asteroids
- assumption: isotropic spectral properties (likely violated)

sky at sub-mm frequencies



German virtual observatory (try yourself!):
`http://gavows2.xray.mpe.mpg.de:8080/planck/`

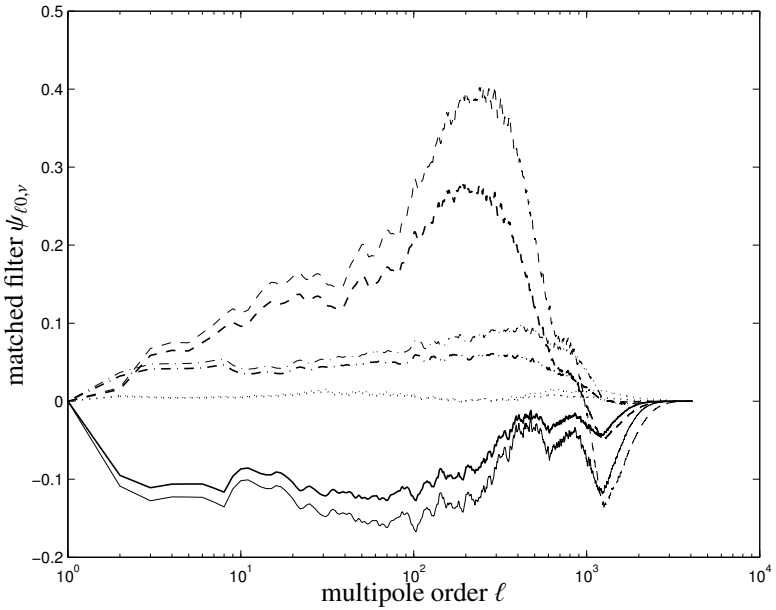
optimised filtering: basics

- convolve sky map $s(\alpha)$ with filter kernel $\psi[R](\alpha)$

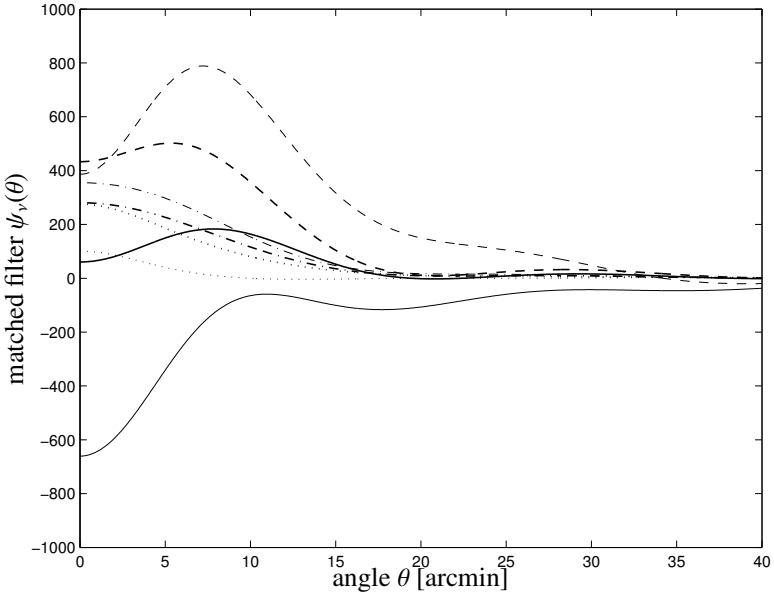
$$w(\alpha, R) = \int \mathrm{d}\Omega \, s(\theta)\psi(\theta - \alpha) = \sum_{\ell=0}^{\infty} \sum_{m=-\ell}^{+\ell} s_{\ell m}\psi_{\ell 0}[R] \cdot Y_{\ell m}(\alpha)$$

- filters should meet 3 (2) requirements
  1. variance $\sigma_w^2(R) = 4\pi \sum_\ell \psi_{\ell 0}^2[R] \cdot C_\ell$ is minimal at scale R_0
  2. $\langle w(\alpha, R_0)\rangle = 4\pi \sum_\ell \psi_{\ell 0}[R] \cdot s(\ell)$ is an unbiased estimator for the peak height $s(\alpha)$
  3. there exists a scale R_0, such that $\langle w(\alpha, R_0)\rangle = \max$
- functional minimisation for obtaining scale-adaptive filter $\psi(\alpha)$ (1-3) and matched filter $\phi(\alpha)$ (1+2)
- pioneered for flat geometry and analytical profiles by Sanz et al.: ApJ 552:484 (2001), and Herranz et al.: MNRAS 336, 1057 (2002) (great read!)

matched and scale-adaptive filtering



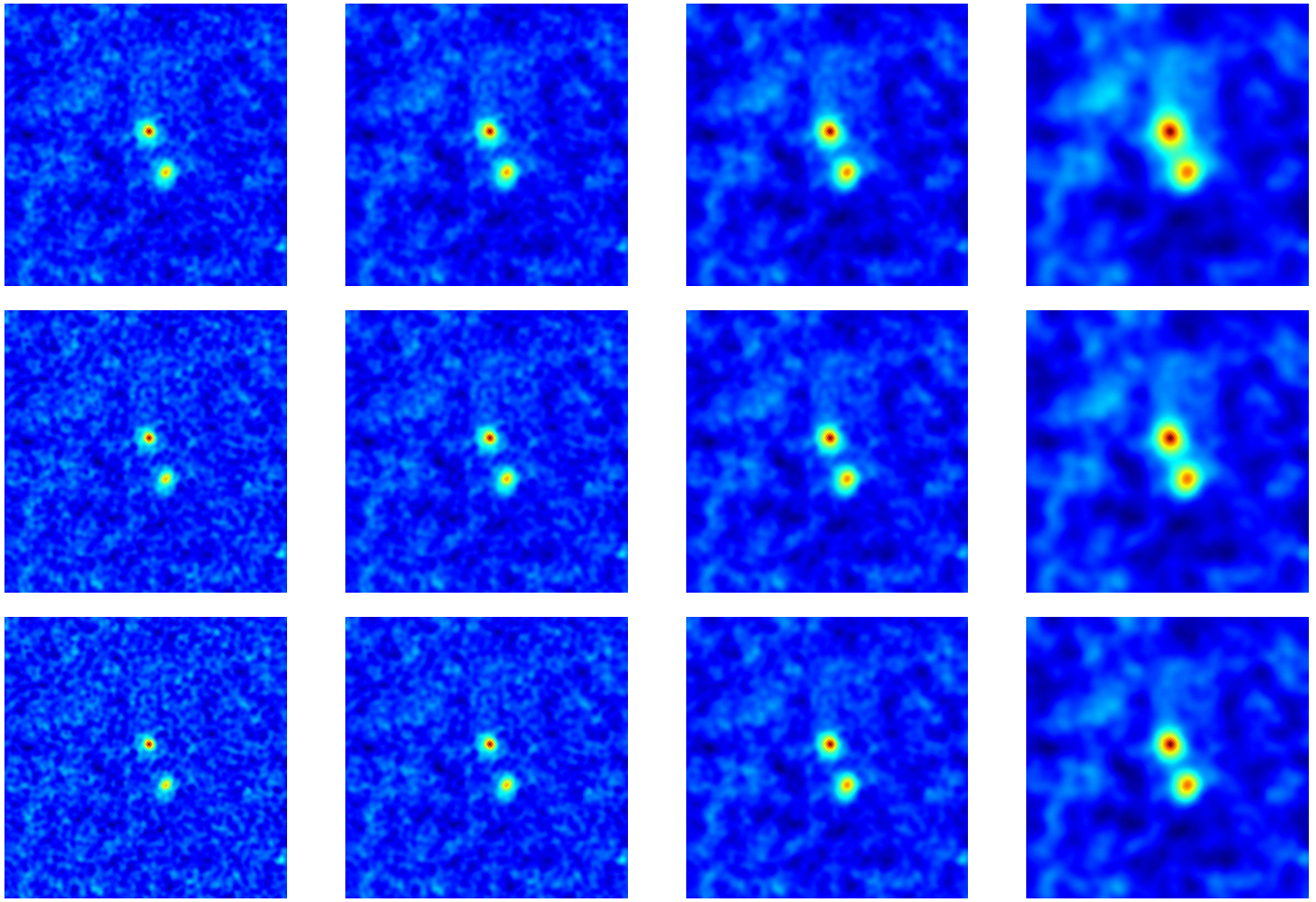
$Y_{\ell m}$-space



real space

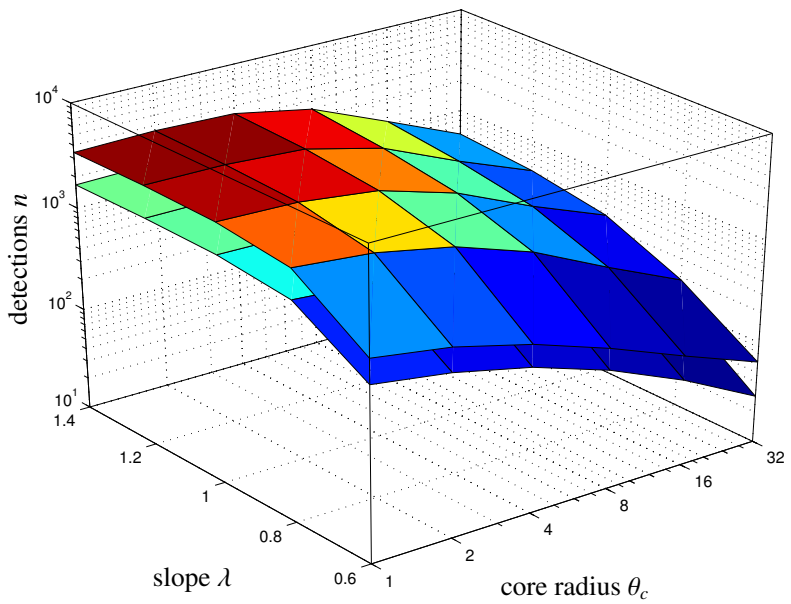
- extended to spherical geometry
- gives filter kernel shape as function of
  - model profile (β-profile works reasonably well)
  - spectral dependence of signal (SZ spectral dependence)
  - power spectra $C_{\nu_1\nu_2}(\ell)$ (45=36+9 spectra)

filtered maps: visual impression

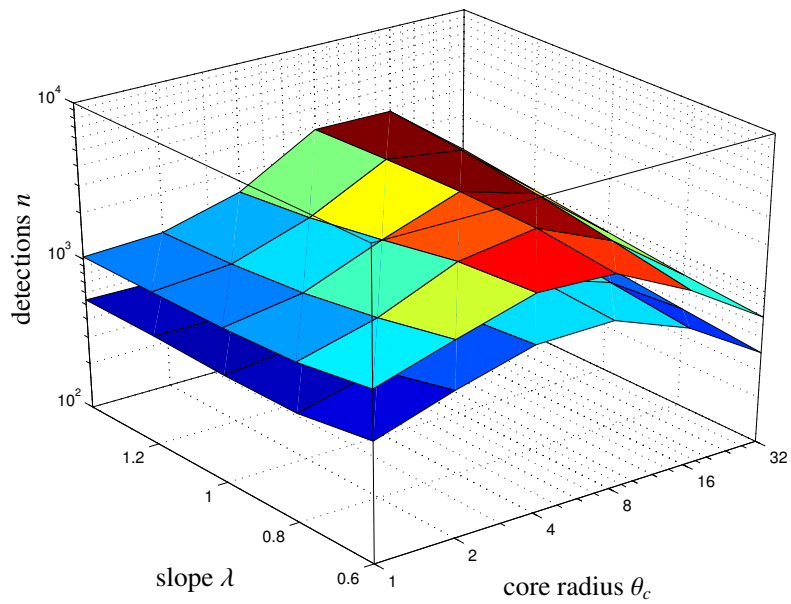


- filters optimised for various (θ_c, λ)-pairs $(y(\theta) \propto (1 + \theta/\theta_c)^{-\lambda})$
- significance varies much! (try to get best lock on cluster)

number of recoveries



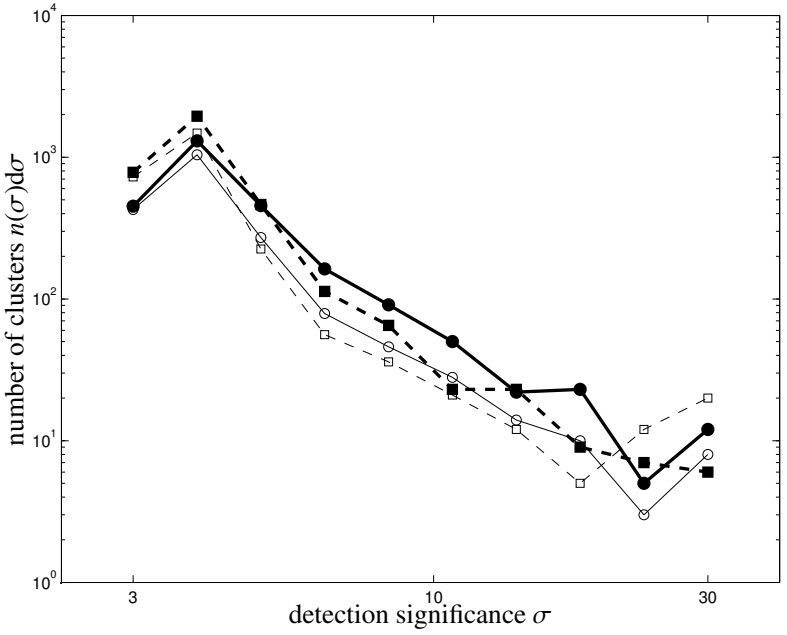
matched filtering



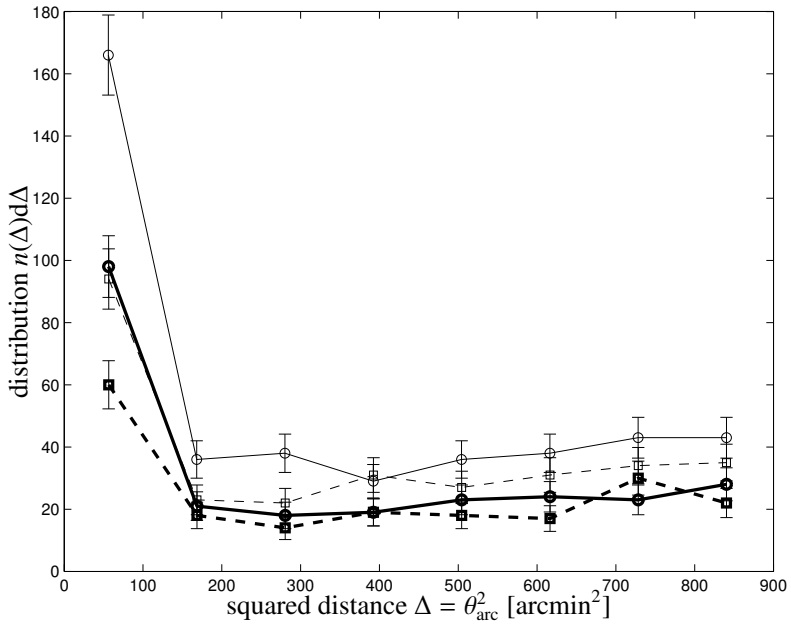
scale-adaptive filtering

- total number: 6000 to 8000 (above 3σ)
- 25% lost when including Galactic foregrounds
- watch out: figures not corrected for multiple detections!

significances and position accuracy



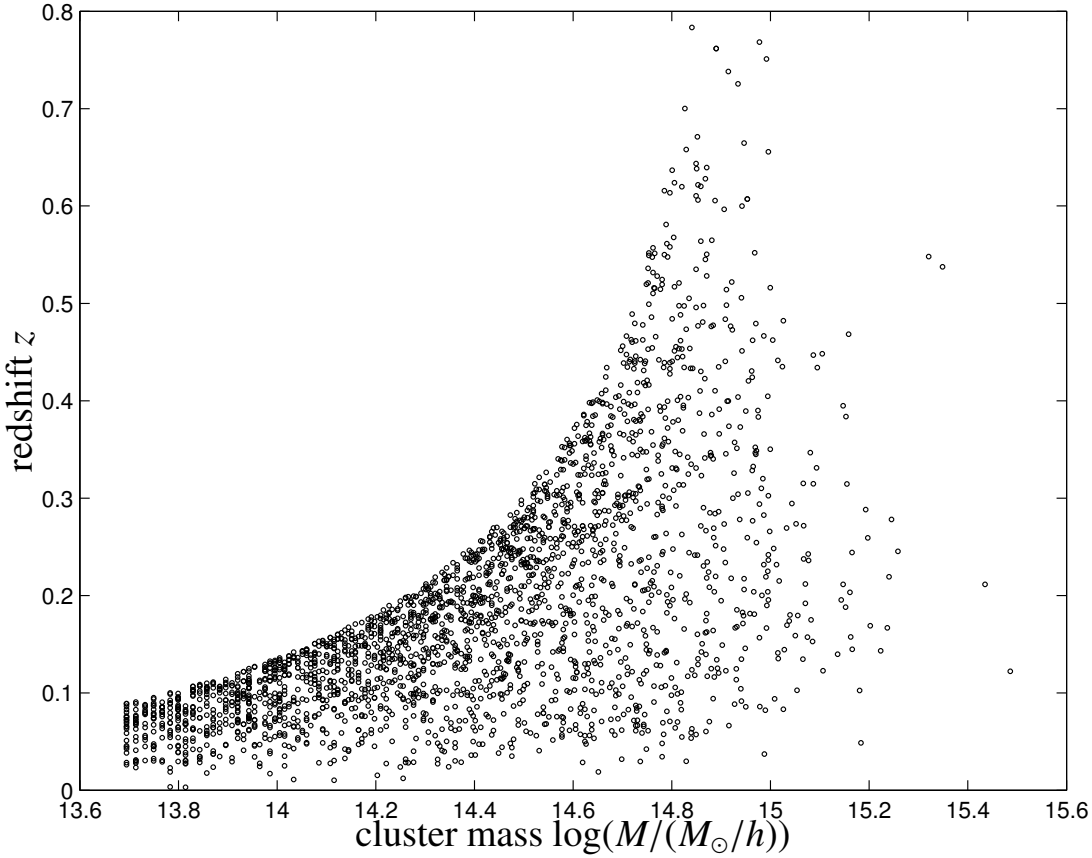
significances



position accuracy

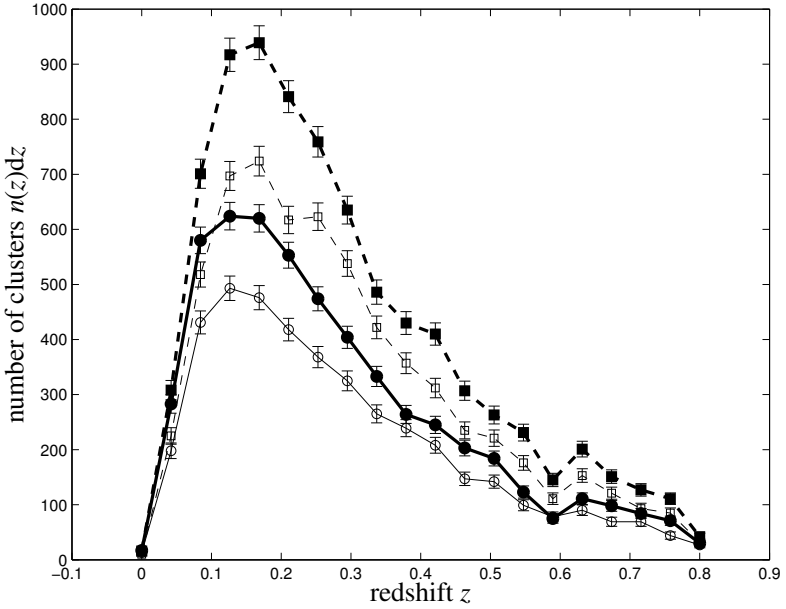
- scale-adaptive filter: many detections at threshold (3σ)
- matched filter: highly significant detections
- position accuracy: most of clusters within $10'$

mass-redshift plane

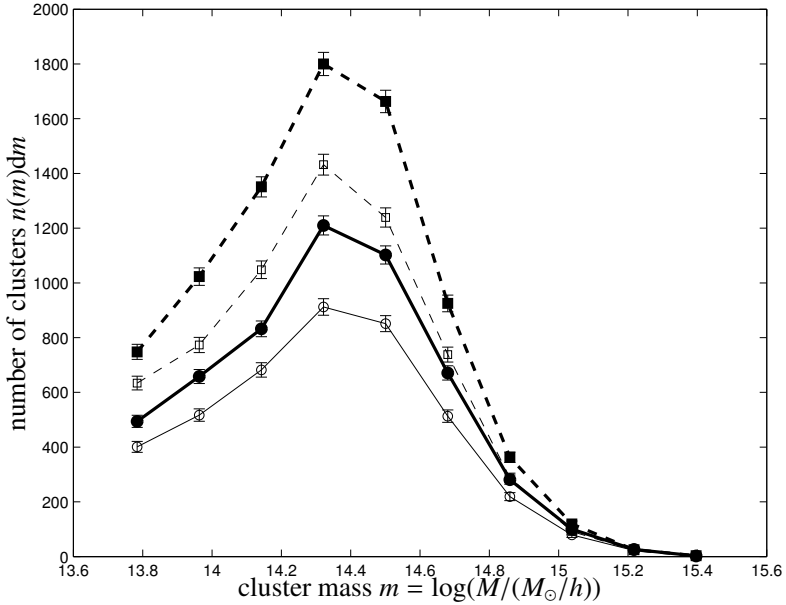


- fairly well-defined region in M-z plane
- population of low-M, z clusters not included in analysis

distributions in mass and redshift



redshift distribution



mass distribution

- high-mass end fairly well sampled
- no detection beyond $z = 0.8$
- large differences between filtering schemes

SZ-observations: PLANCK and ALMA

- ALMA configuration for SZ-observations:
  compact, μK-sensitivity, 10 arcsec resolution, 1 arcmin fov
- resolution: improvement compared to PLANCK by 30!
- tiny fov $\longrightarrow$ position of PLANCK clusters too coarse for follow-up
- interesting topics:
  - cluster substructure, non-pressure equilibrium features
  - internal dynamics and turbulence via kinetic SZ

summary and conclusion

- PLANCK will yield a unique cluster sample with ~ 8000 entries (more than Abell's catalogue, larger than all X-ray catalogues)
- very realistic simulation, observational + instrumental issues included
- all-sky Sunyaev-Zel'dovich maps will be publicly available soon
- 3 new foregrounds: carbon monoxide, free-free and planets/asteroids will be made public in the near future
- fancy filtering: scale-adaptive and matched multifilters
- possible to perform calculations with up to 5×10^7 pixels and $\ell \simeq 4096$ with PLANCK simulation tools
- paper submitted to MNRAS (see `astro-ph/0407089` and `astro-ph/0407090`), $3^{\rm rd}$ paper to follow

SZ SKY IS GOING TO BRIGHTEN UP!