Gas & Gravity
new techniques for secondary anisotropies in the CMB

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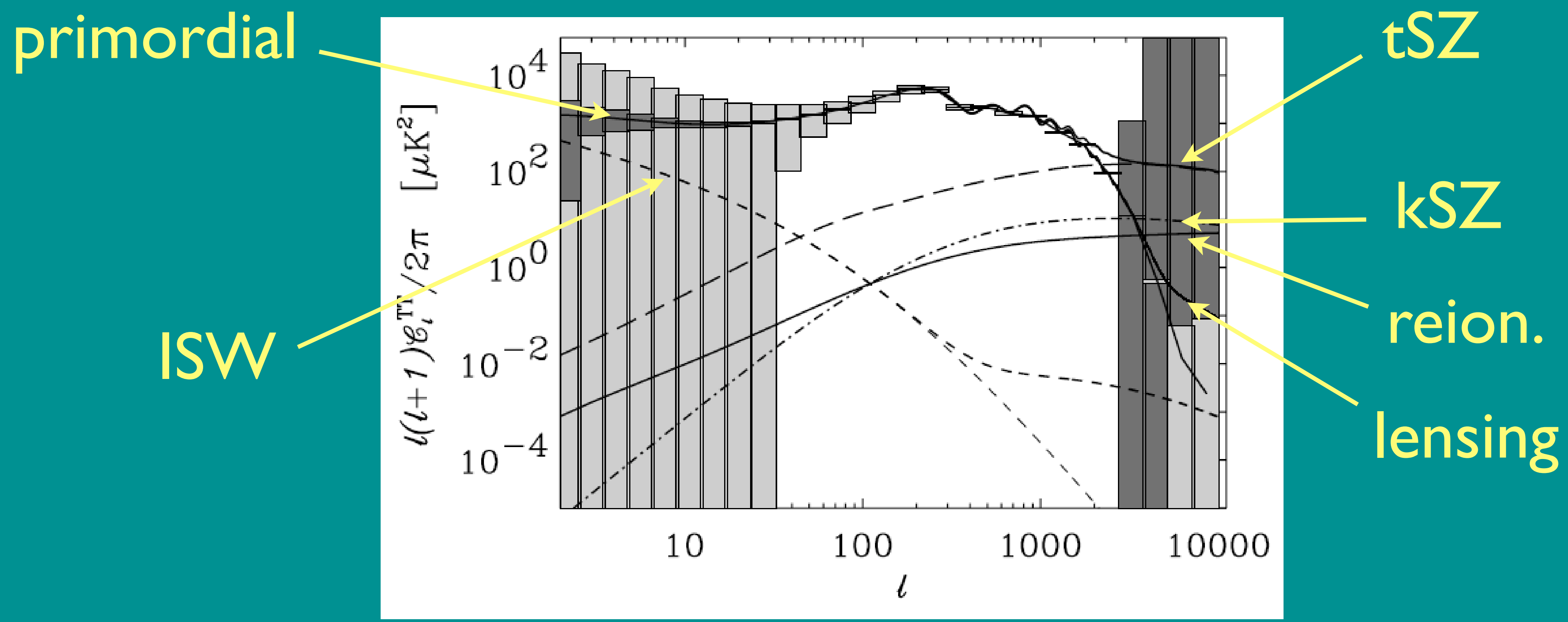
(*: wonderful person)

the New Era

Silk dampening mutes primordial (SLS) fluctuations
three signals at arcminute scales



the Backlight

at ell of 3000 these are “shadows”
signals do not die off with redshift

[
compare galaxy surveys and even high-z 21 cm studies:
always fighting r-squared dimming
]

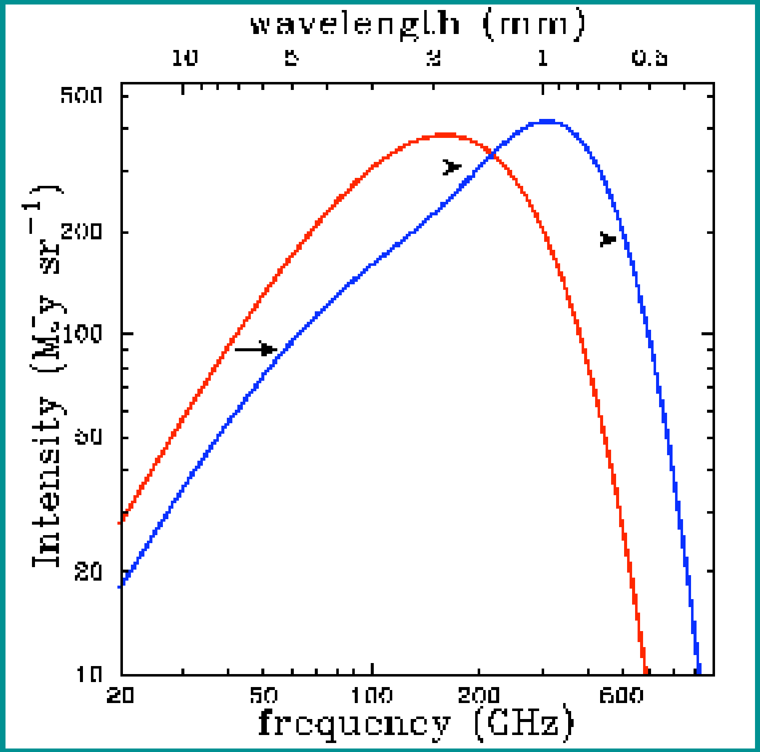
extracting these signals: difficult but rewarding

thermal SZ distortions

hot gas in X-ray clusters

random thermal motions
cancel to first order —
signal goes as *square* of velocity
and breaks blackbody

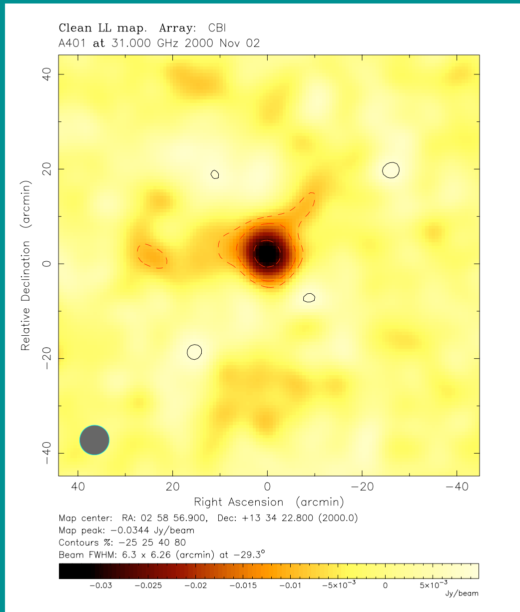
$$\langle v \rangle = 0; \langle v^2 \rangle \neq 0$$



sensitive to high-pressure gas
deep in potential wells

Compton "y" scales as density
times temperature

selling the tSZ to the NSF



cluster identification + gas physics

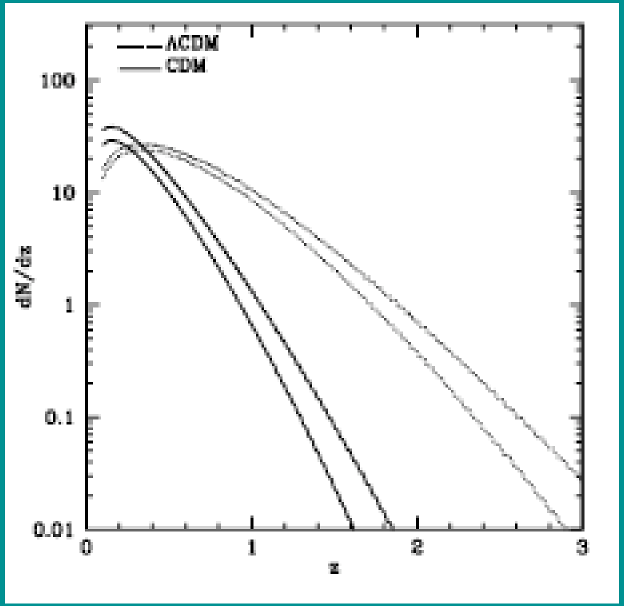
=

cluster demographics

tells you σ_8 as a function of redshift

sensitive probe of dark energy

homogenous expansion E.O.S.



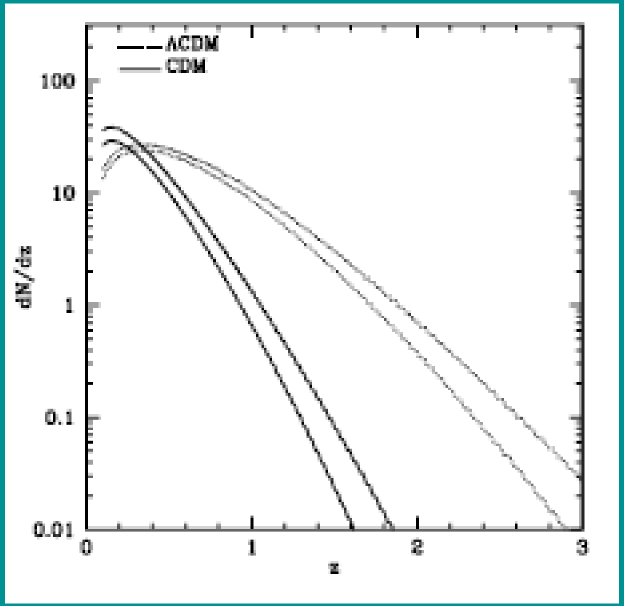
selling lensing to the tSZ

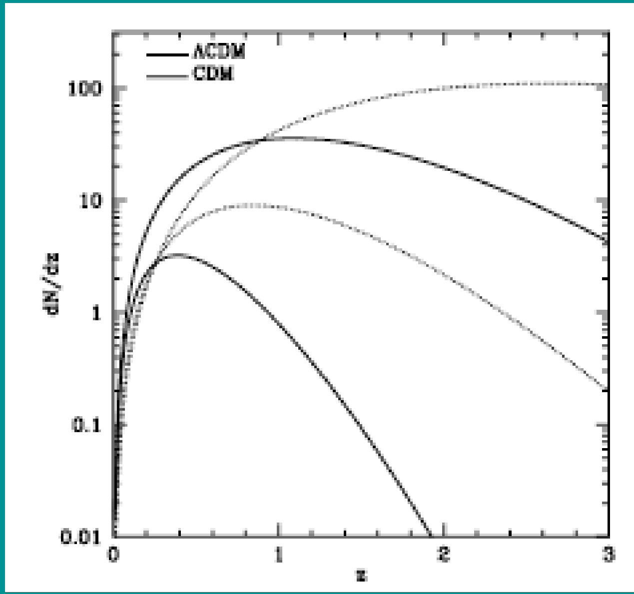
(Hu, DeDeo and Vale 2007)

sources of noise for tSZ : observational and systematic

need to know gas physics

thermal profile, evolution of entropy &
local baryon-DM ratio

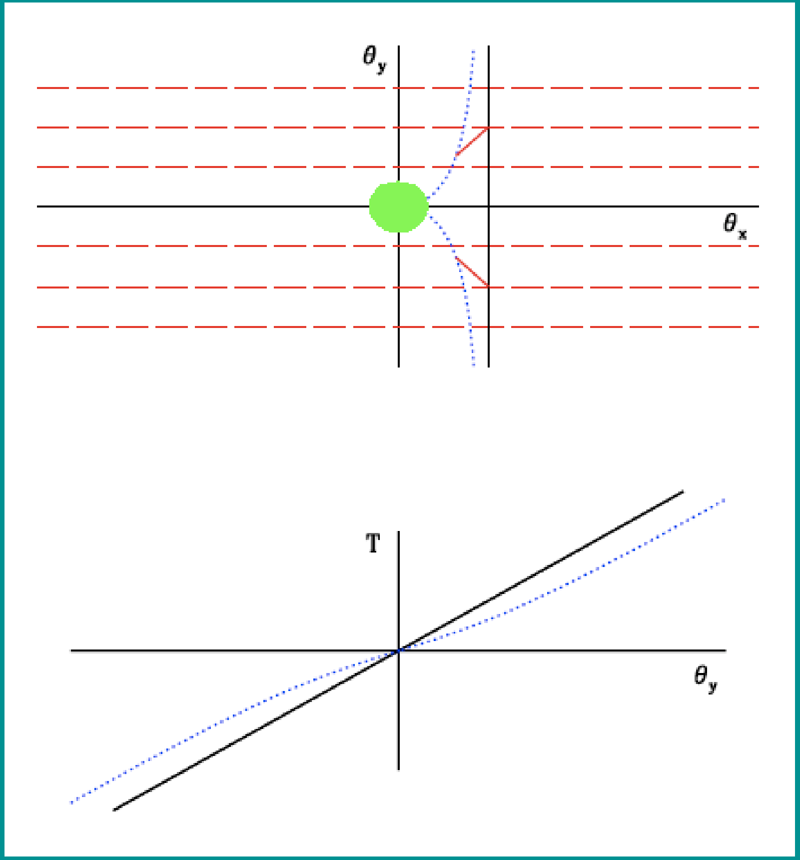




selling lensing to the tSZ

(Hu, DeDeo and Vale 2007)

gravitational lensing : best seen in "four point"



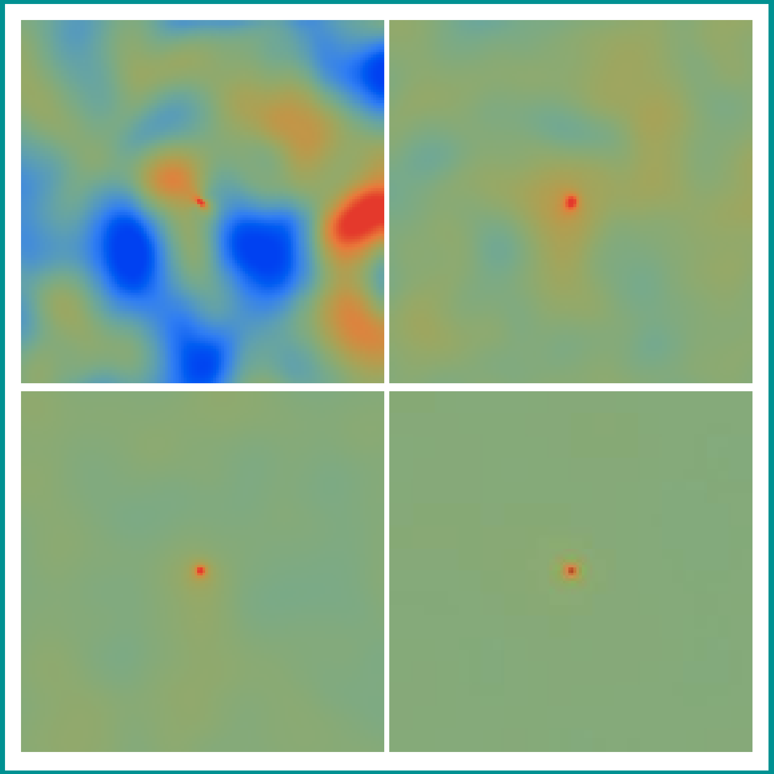
if there is a large-scale (degree or sub-degree) gradient, lensing makes a "spike"

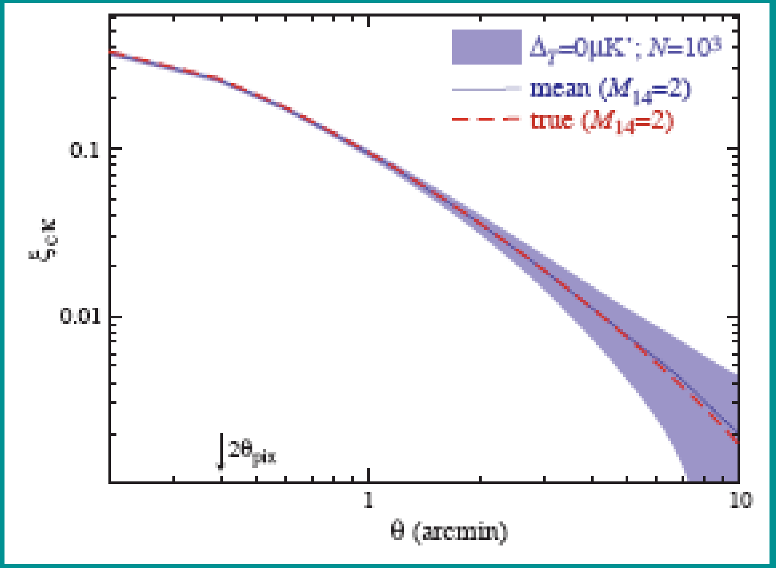
use the gradients to search for these spikes

selling lensing to the tSZ

(Hu, DeDeo and Vale 2007)

gravitational lensing : noisy, but very different systematics



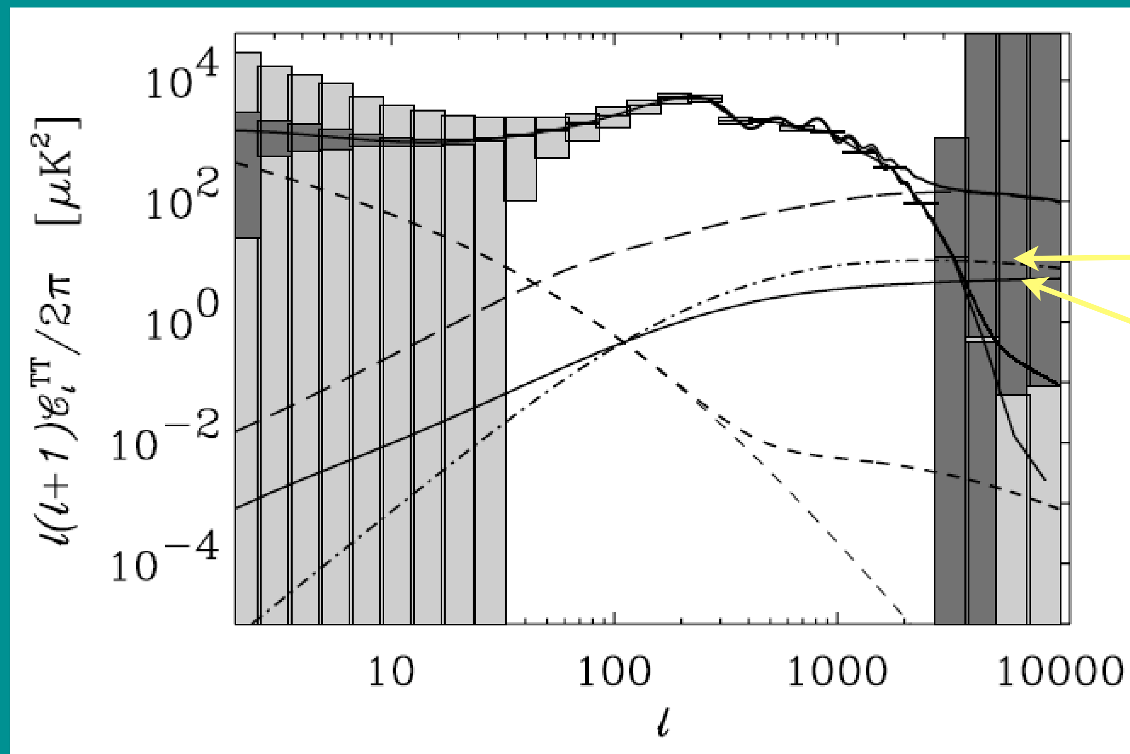


better? not quite — but definitely competitive with tSZ and a way to "make firm" your dark energy

beyond the tSZ : kSZ & reionization

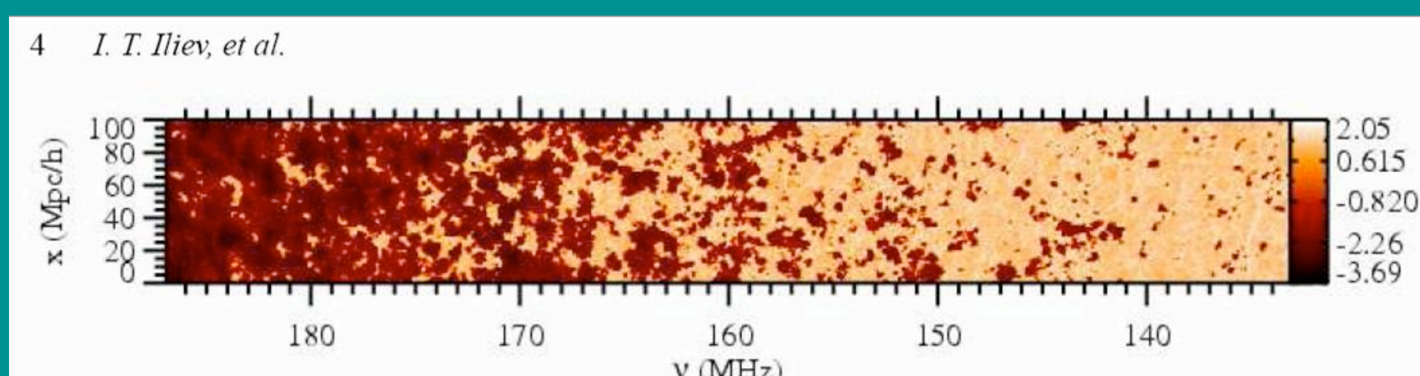
(DeDeo et al. 2005–2007)

an uncertain background!



kSZ

reion.



beyond the tSZ : kSZ ~~& reionization~~

(DeDeo et al. 2005–2007)

the "first order" brother to the tSZ:

tSZ: hot gas, random motion.

second order term in relativistic doppler shift;
non-thermal spectrum, parametrize with "*y*"

traces pressure

kSZ: non-relativistic bulk flows; thermal spectrum
(though second-order corrections *may* be required)

traces momentum

two ways of looking at the kSZ

1. the “classical” version (Ostriker & Vishniac, 1987)

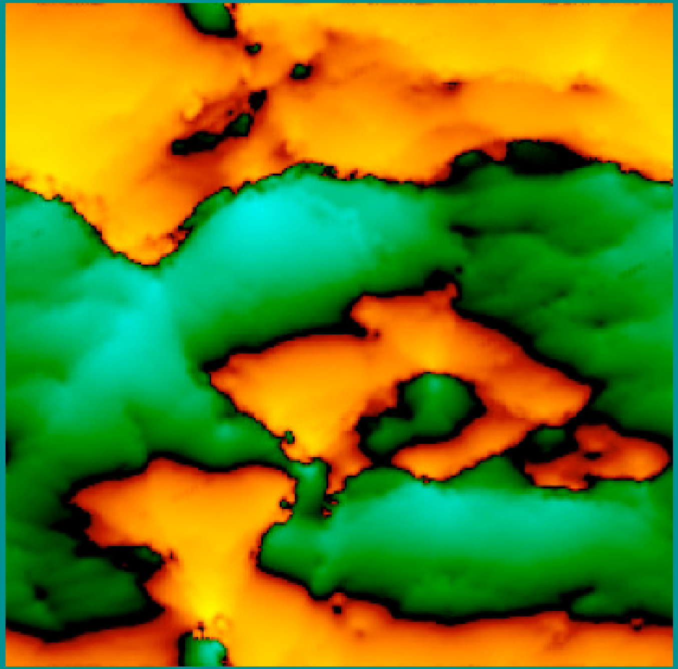
    - extract from a survey in Fourier space

2. the “modern” fashion (e.g., Jimenez, 2005)

    - “circle clusters, look behind”

the classical version (1)

problem: in the linear regime, velocity flows are linear



line of sight (up the screen) velocity
green, towards; orange, away

flows are *gradient*;
v and **k** are aligned:

$$\mathbf{v}(\mathbf{k}, a) \propto H(a) \frac{d \ln D}{d \ln a} \delta(k) \frac{\mathbf{k}}{k^2}$$

in the Limber approximation, should be no signal!
(Kaiser, 1984)

the classical version (2)

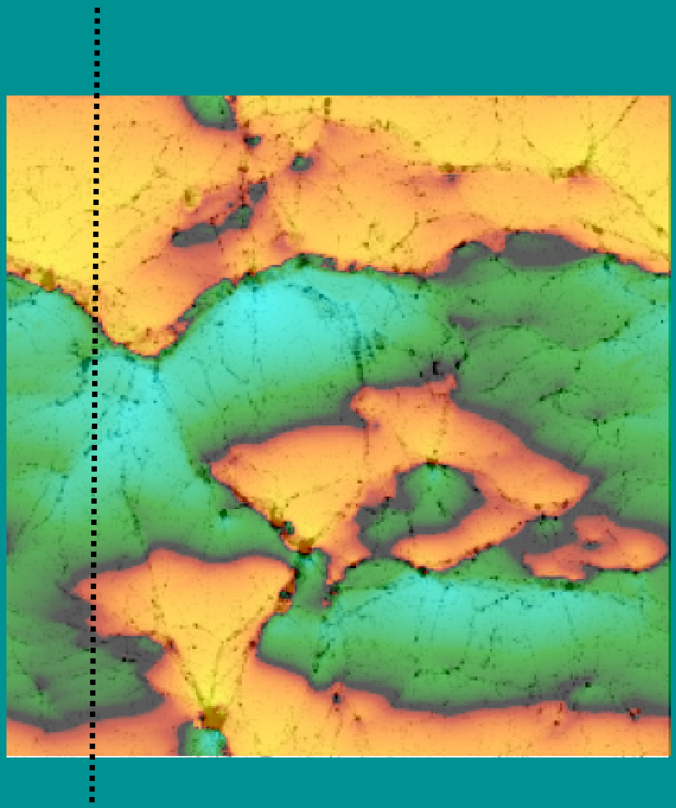
insight (Ostriker & Vishniac, 1987):

kSZ traces the *momentum*; so look to the non-linear:

$$T_{\rm kSZ} \propto (1 + \delta)v$$

pure gradient

"curl" component emerges



velocity averages out, but not momentum; projected power of momentum "curl" gives CMB fluctuations

the classical version (3)

manipulating mathematics, the kSZ signal is well-approximated by

$$P_{\mathrm{curl}}(k) = v_{\mathrm{rms}}^2 P_{\delta\delta}^{\mathrm{nl}}(k)$$

(*i.e.*, non-linear density spikes moving in a linear velocity field.)

insight

the kSZ is fundamentally non-linear

(how to model? how to find? : crosscorrelation)

the modern fashion

“just circle the overdensities”: we know clusters and galaxies are moving! Just circle them and “look behind” (with some appropriate filter to evade primordial power.)

don’t try to predict the details of high-order correlations, just work from (possibly environmentally dependent) velocity dispersion predictions

three ways to detect the kSZ

1. correlate the a_{lm}s
DeDeo, Trac & Spergel (2005)

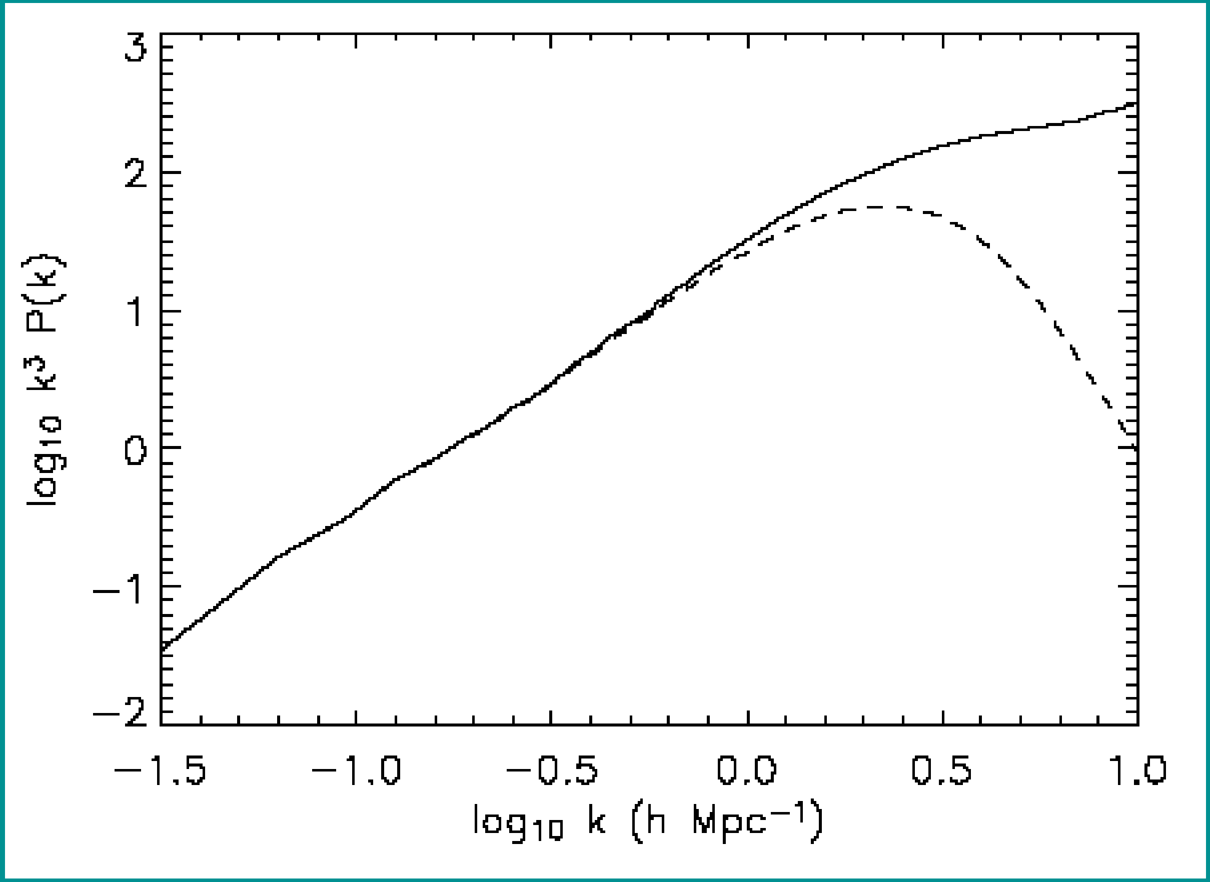
2. circle the clusters
Jimenez et al. (2005)

3. reconstruct the velocity field
DeDeo & al. (2006, 2007)

important "global" questions

- how does ionization fraction evolve over time? (feeds into cosmological parameters)
- how does gas trace matter?

(effective, redshift-independent smoothing length is a good [1-5%] guess.) — approx 400 kpc scale.



1. correlate the a_{lm}s

DeDeo, Trac & Spergel (2005)

Slightly tricky: galaxies can be moving towards or away.

Hence: must correlate velocity squared: $\langle T^2 \delta_g \rangle$

$$\langle T^2 \delta_g \rangle = (\mathrm{bias}) \langle v v \delta_m \delta_m \delta_m \rangle \approx v_{\mathrm{rms}}^2 \langle \delta_m \delta_m \delta_m \rangle$$

Need to know the matter *bispectrum* to determine cosmological parameters.

Do simple "tomography": $\Delta z \approx$ *0.1* despite need to fit a wide variety of parameters for both the physics (reionization redshift, time evolution, gas smoothing scale, linear galaxy bias) and cosmology (w, w', and so forth) — excellent constraints:

parameter	fiducial value	A error	B error
$\Omega_m h^2$	0.1400	0.0016	0.0016
$\Omega_b h^2$	0.02400	0.00019	0.00019
$d_{\rm LSS}$	1.390 Gpc	0.029 Gpc	0.023 Gpc
σ_8	0.84	0.10	0.054
w	-1.000	0.099	0.081
dw/da	0.00	0.18	0.18
"c"	0.00	1.1	0.48
$\sigma_{\rm sm}$	0.350 $\rm Mpc^{-1}$	0.071 $\rm Mpc^{-1}$	0.062 $\rm Mpc^{-1}$
$z_{\rm ri}$	17.00	0.18	0.17
b	1.00	0.18	0.10

(A: individually; B: using cross-correlation info.)

Bulk flows are large-scale: can dump "scary" small-scales and still learn a great deal ⇒

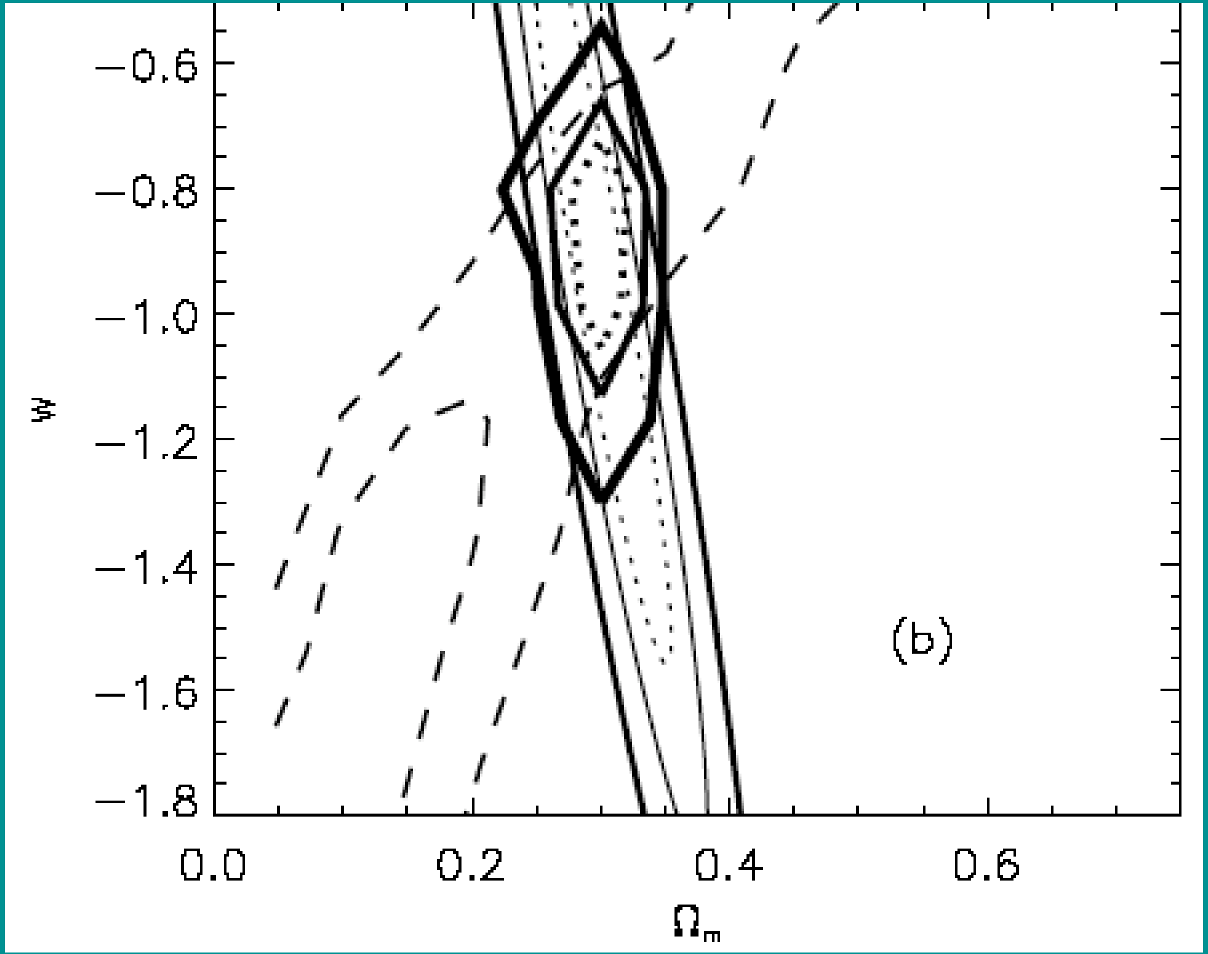
parameter	$1h$ $\rm Mpc^{-1}$A error	$1h$ $\rm Mpc^{-1}$B error
$\Omega_m h^2$	0.0021	0.0017
$\Omega_b h^2$	0.00043	0.00020
$d_{\rm LSS}$	0.032 Gpc	0.029 Gpc
σ_8	0.55	0.22
w	0.11	0.10
dw/da	0.19	0.19
"c"	n.c.	1.4
$\sigma_{\rm sm}$	0.81 $\rm Mpc^{-1}$	0.14 $\rm Mpc^{-1}$
$z_{\rm ri}$	0.39	0.19
b	0.72	0.31

2. "circle the clusters"
Jimenez et al. (2005)

The "opposite" idea: look for temperature increments or decrements behind individual clusters.

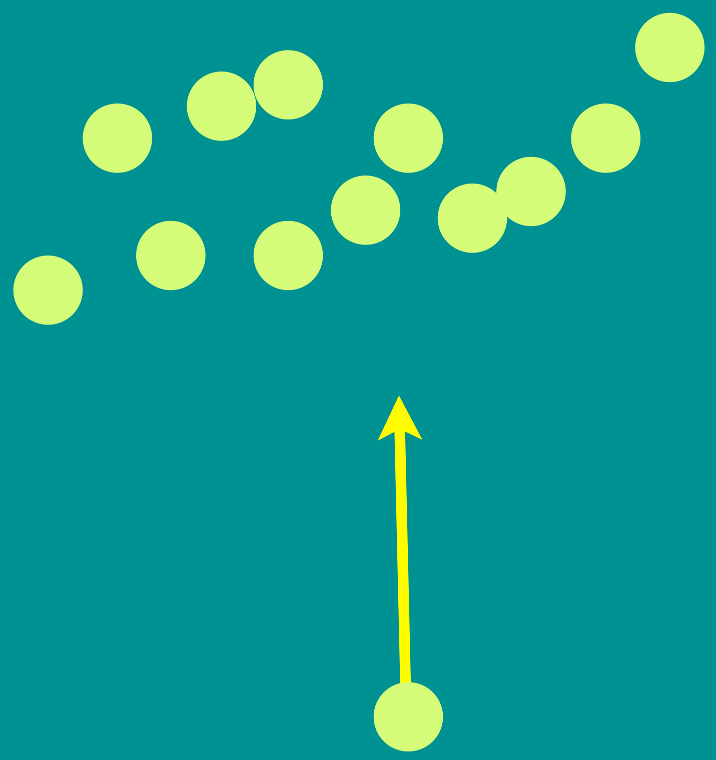
Similar constraints ⇒

(SPT, WMAP; clusters identified with tSZ.)

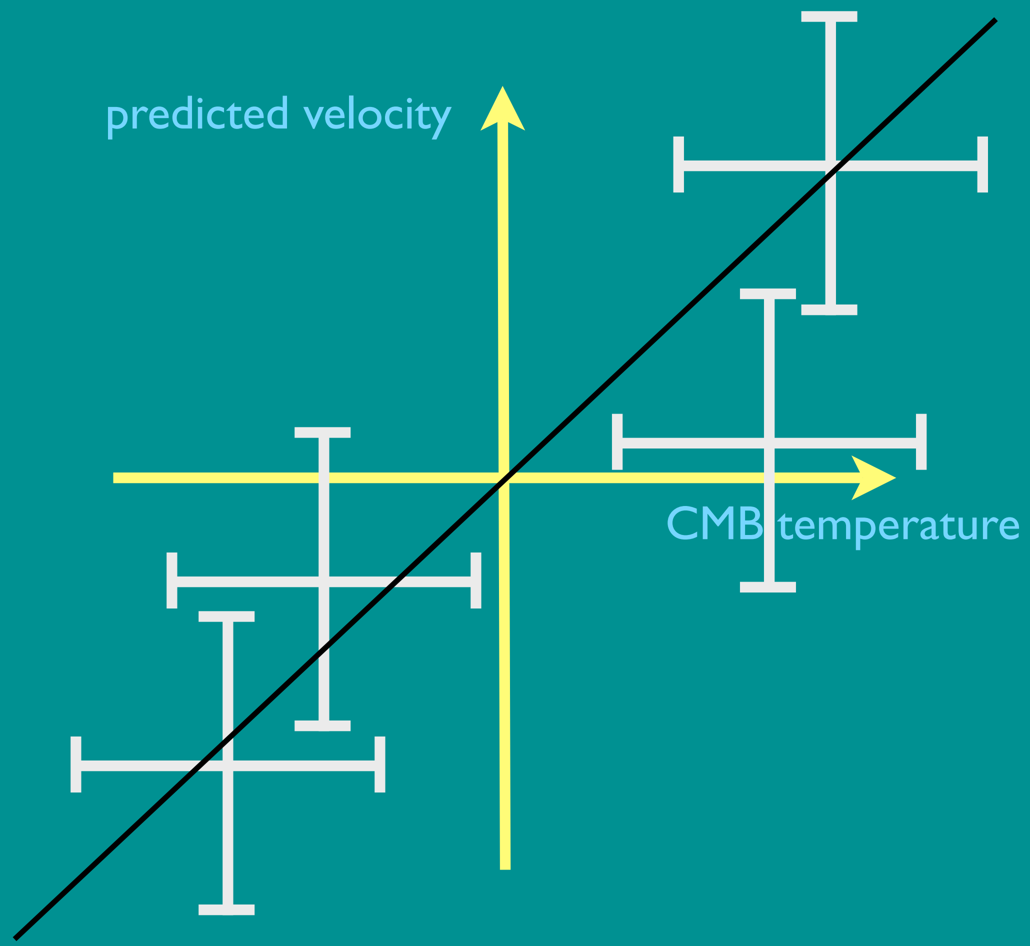


3. reconstruct the velocity field
DeDeo, Ho [& Spergel] (2007, in prep)

Ambitious — exciting: why not use the density field on large scales to *reconstruct* the velocity field?



need $\Delta z \approx 0.01$



3. reconstruct the velocity field
DeDeo, Ho [& Spergel] (2007, in prep)

Advantages: *more information*. Get a handle on the phase of the velocity, as well as a direct (intuitive) study of both the evolution of gas, and the acceleration of flows.

- how well can we determine the velocity field?

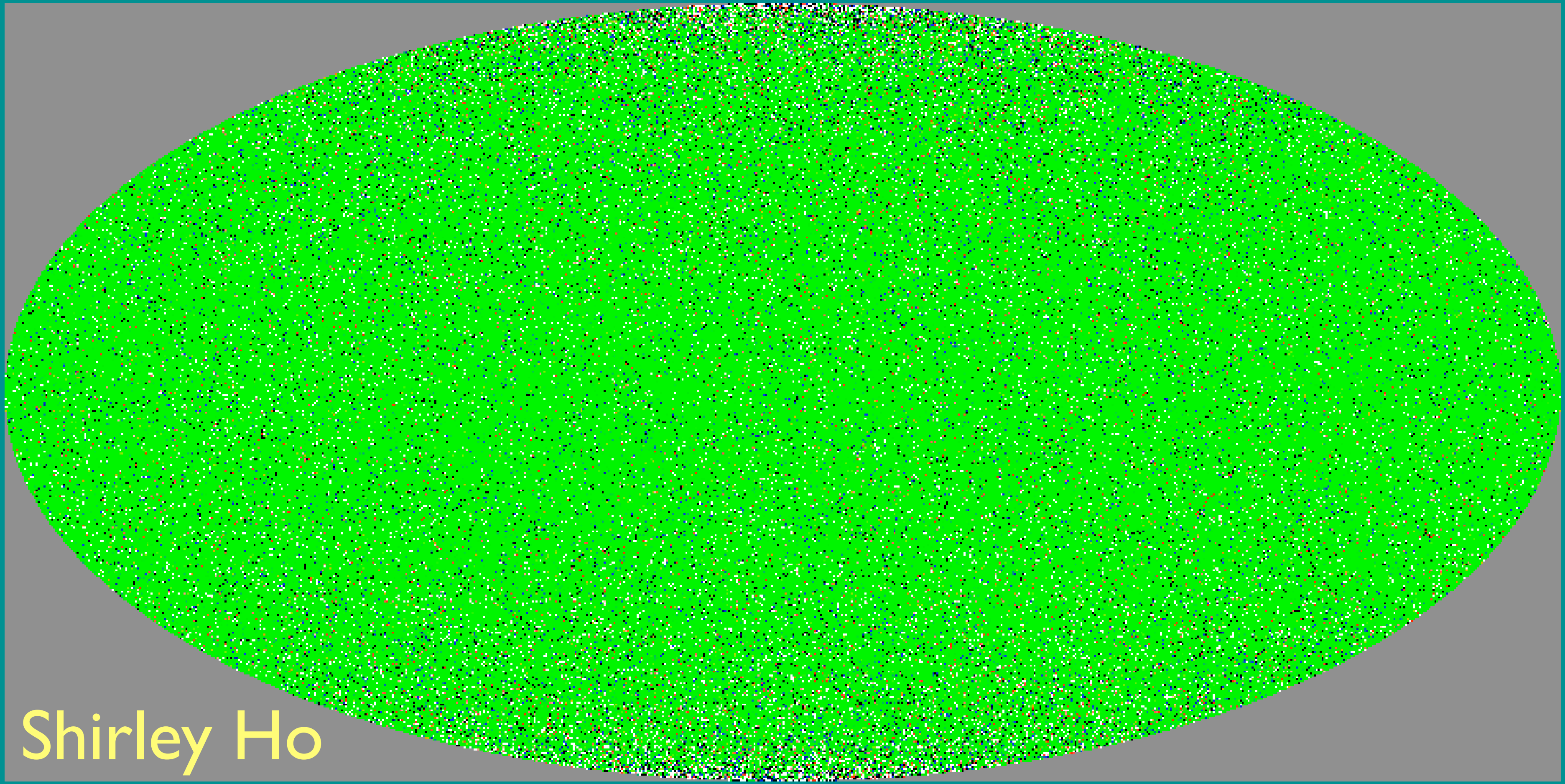
    ⇒ Poisson noise

    ⇒ avoid small-scale non-linearity

- how well can we filter and model?

reconstruction

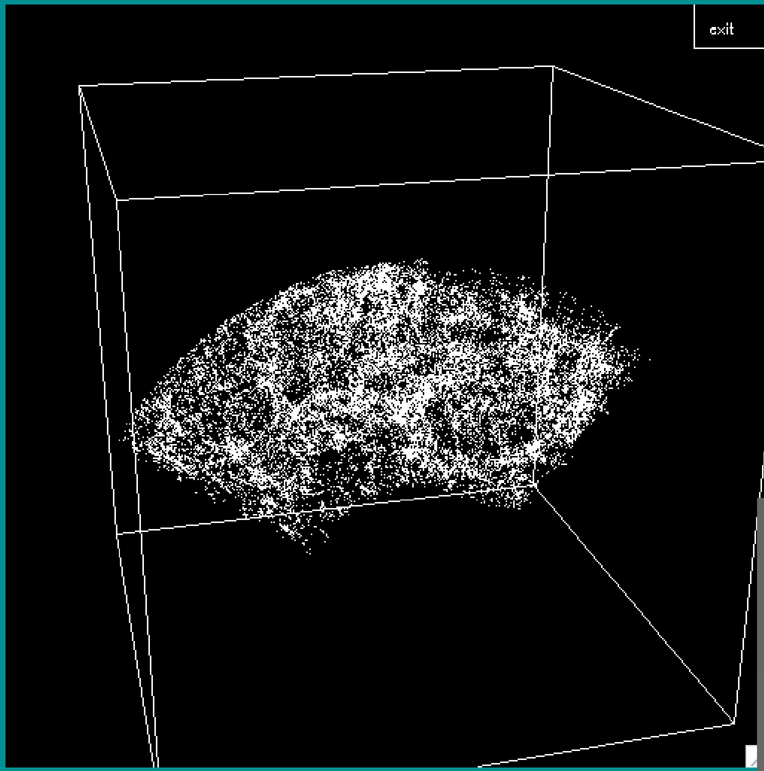
• could just use the Tully-Fisher relation to subtract off the Hubble flow — use this to make a template to tell you where to look in WMAP



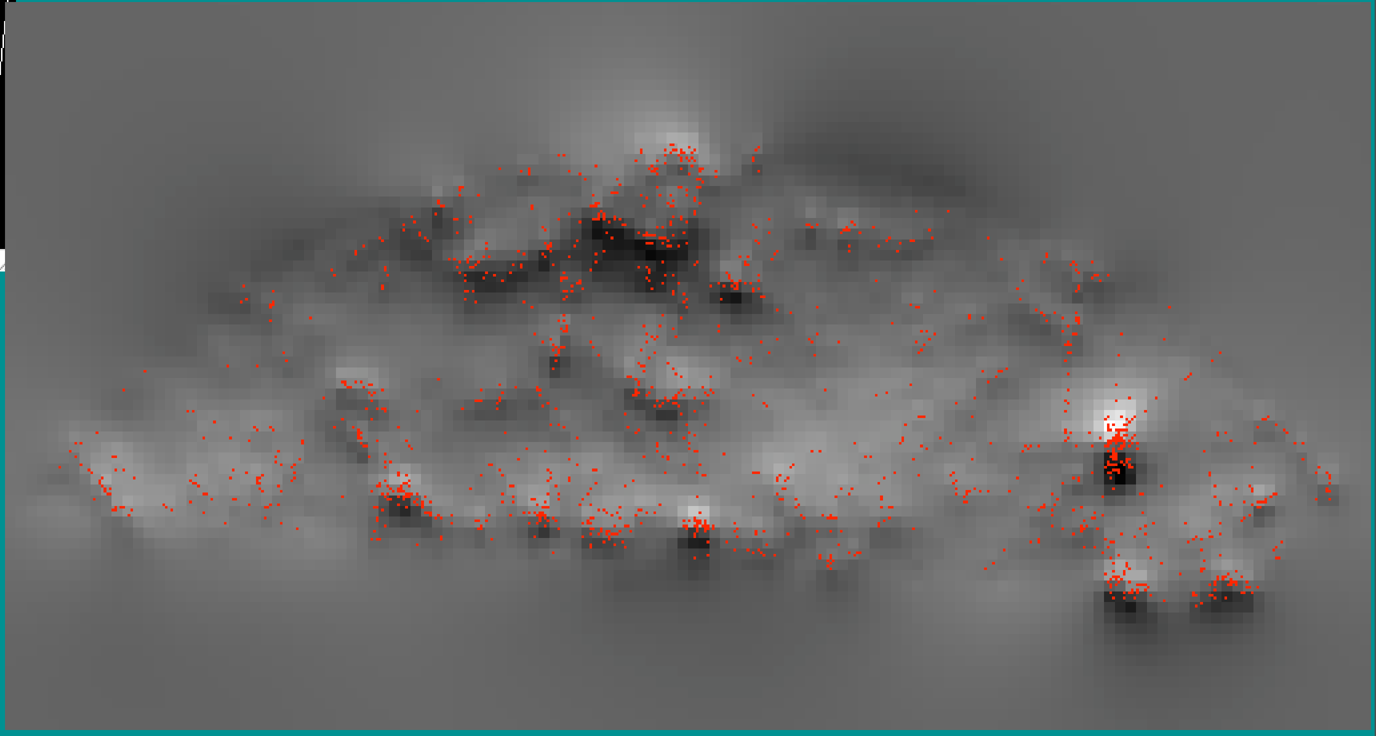
reconstruction

- use the linear density-velocity relationship — take the density, pad, and transform

$$\mathbf{v}(\mathbf{k}, a) \propto H(a) \frac{d \ln D}{d \ln a} \delta(k) \frac{\mathbf{k}}{k^2}$$



SDSS volume-limited reconstruction

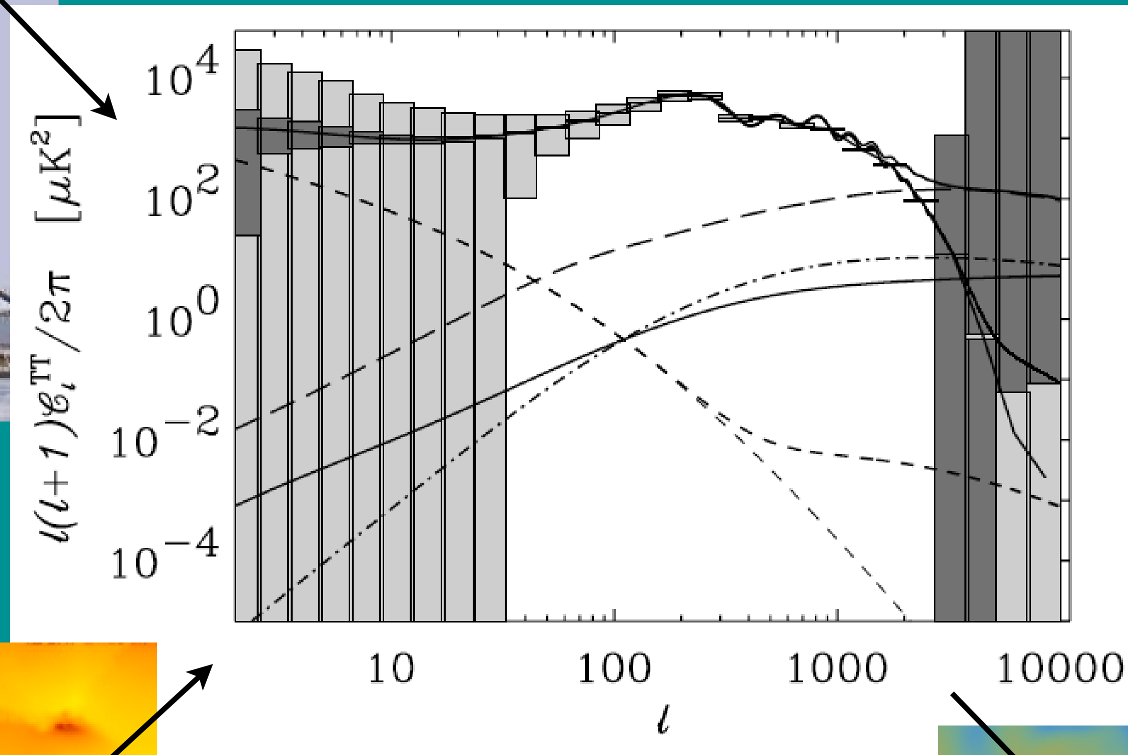


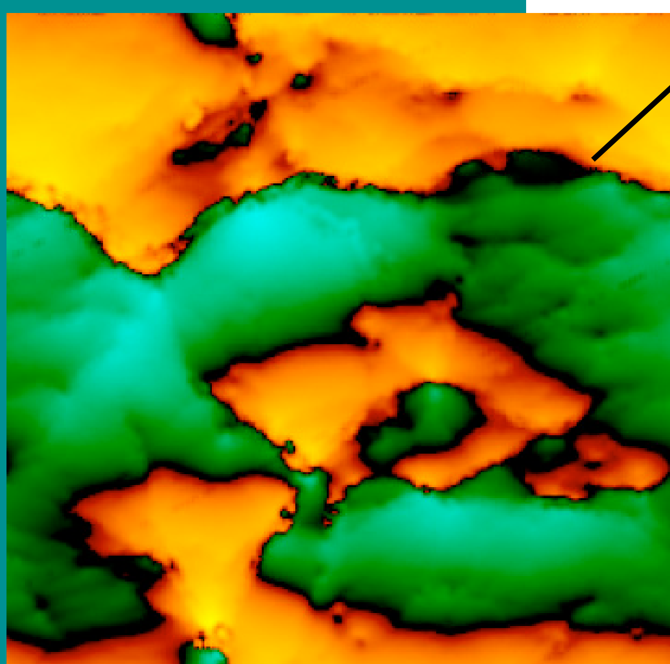
where we stand today (6 Nov 2007)

anticipated WMAP/SDSS : 2σ
ACT/SALT : 40σ+

don't touch that dial (arXiv)

Summary





Gas

&

Gravity!