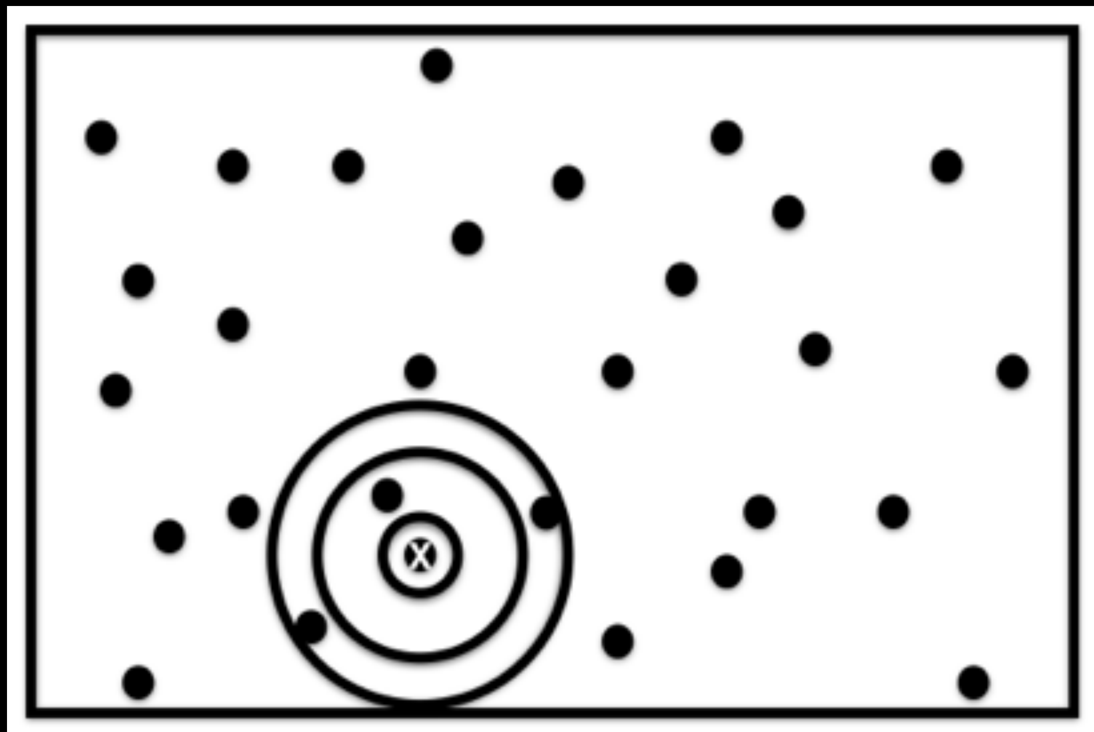
ZACHARY SLEPIAN
EINSTEIN FELLOW, LBNL

THE MISSING SATELLITE PROBLEM RE-EXAMINED

NORDITA
28 JULY 2017

WITH ANDREW SONG, MATT CRAIGIE, LEHMAN GARRISON, & DANIEL EISENSTEIN

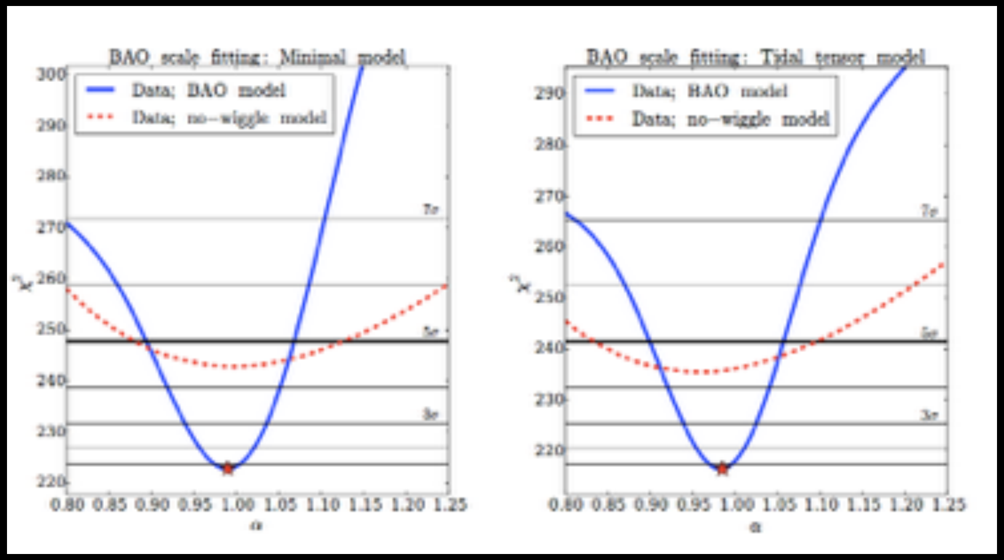
BUT FIRST, A MESSAGE FROM OUR SPONSORS . . .HIGHER-POINT STATS



Estimate 3PCF around a given galaxy by binning density into spherical shells and then expanding angular dependence in spherical harmonics

3PCF: **ZS**+DE16a, with FTs 16b

Full redshift space 3PCF: **ZS**+DE17



$$\text{3PCF multipoles} = \sum_m a_{lm}(r_1) a^*_{lm}(r_2)$$

$$\text{4PCF harmonics} = \sum_m \begin{pmatrix} l_1 & l_2 & l_3 \\ m_1 & m_2 & m_3 \end{pmatrix} a_{l_1 m_1}(r_1) a_{l_2 m_2}(r_2) a_{l_3 m_3}(r_3)$$

NPCF: **ZS,** DE, RM Cahn17

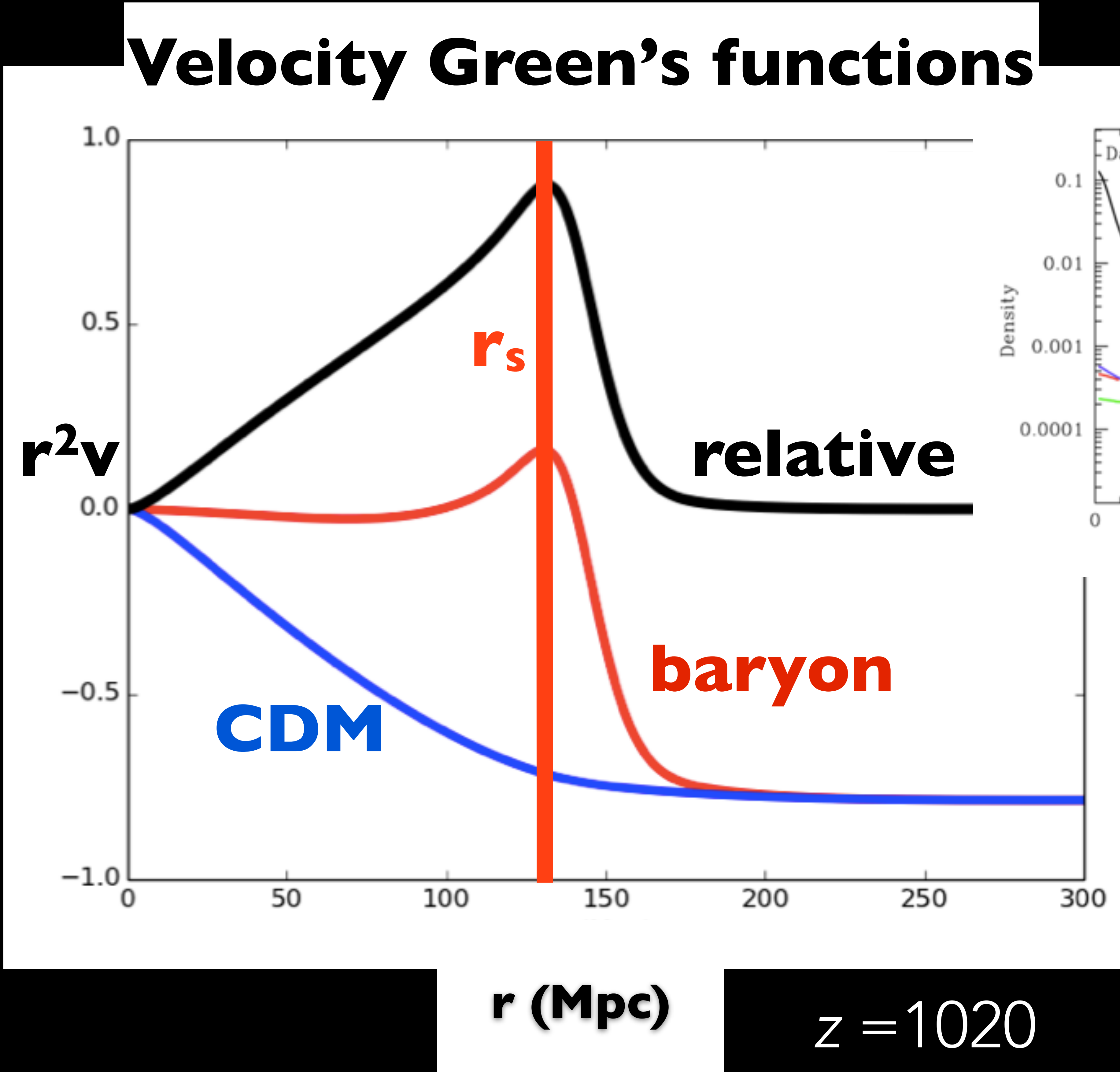
AND NOW TO OUR FEATURED PROGRAMME . . .

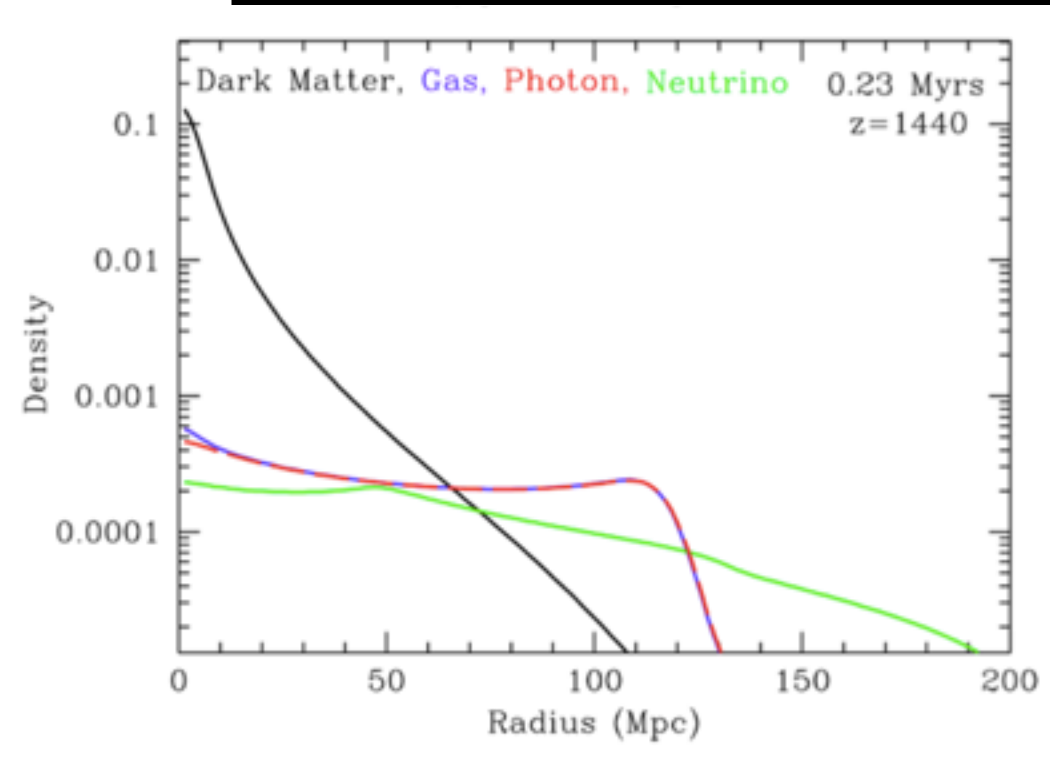
Well-known problem with CDM: excess of small halos predicted by simulations relative to observations

Could be baryon feedback, could be reionization, could be modified gravity . . .

One piece of physics we *know* is there has generally not been included

BARYON-CDM RELATIVE VELOCITY

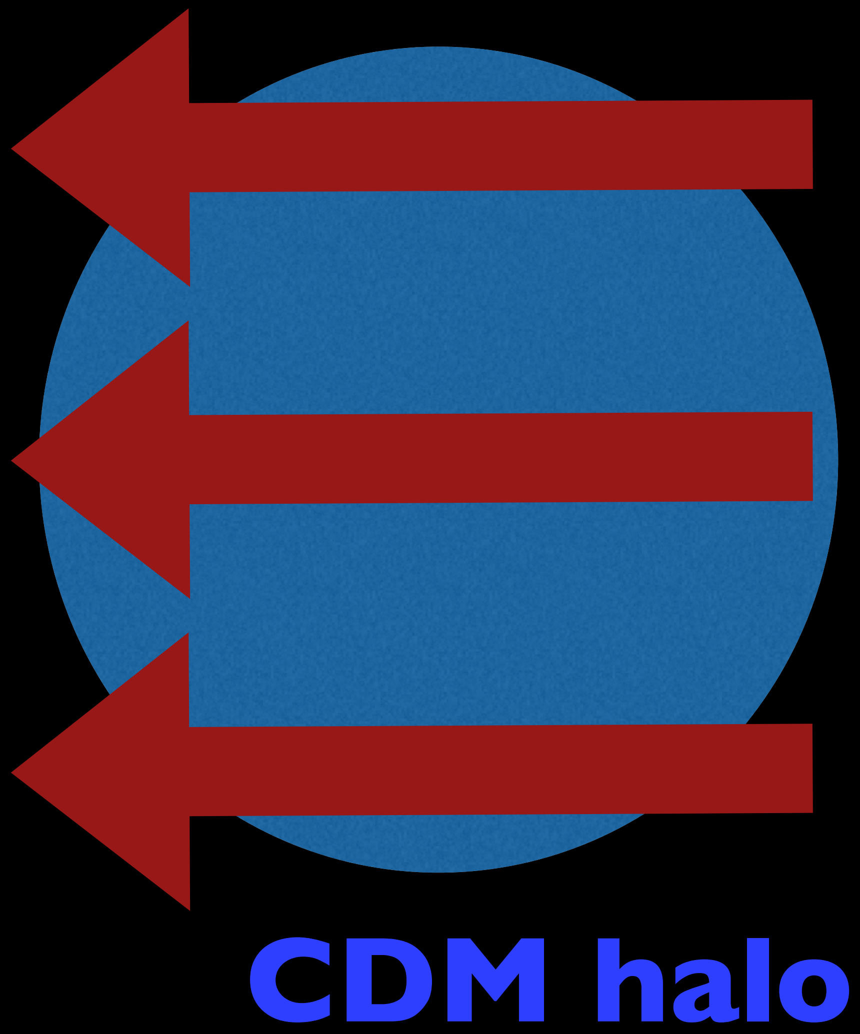




Baryon-photon pulse outgoing

$z = 1020$

Figures: **ZS**&DE 2015a,
Eisenstein Seo & White 2007, **ZS &** DE 2016
RV effect: Tseliakhovich & Hirata 2010

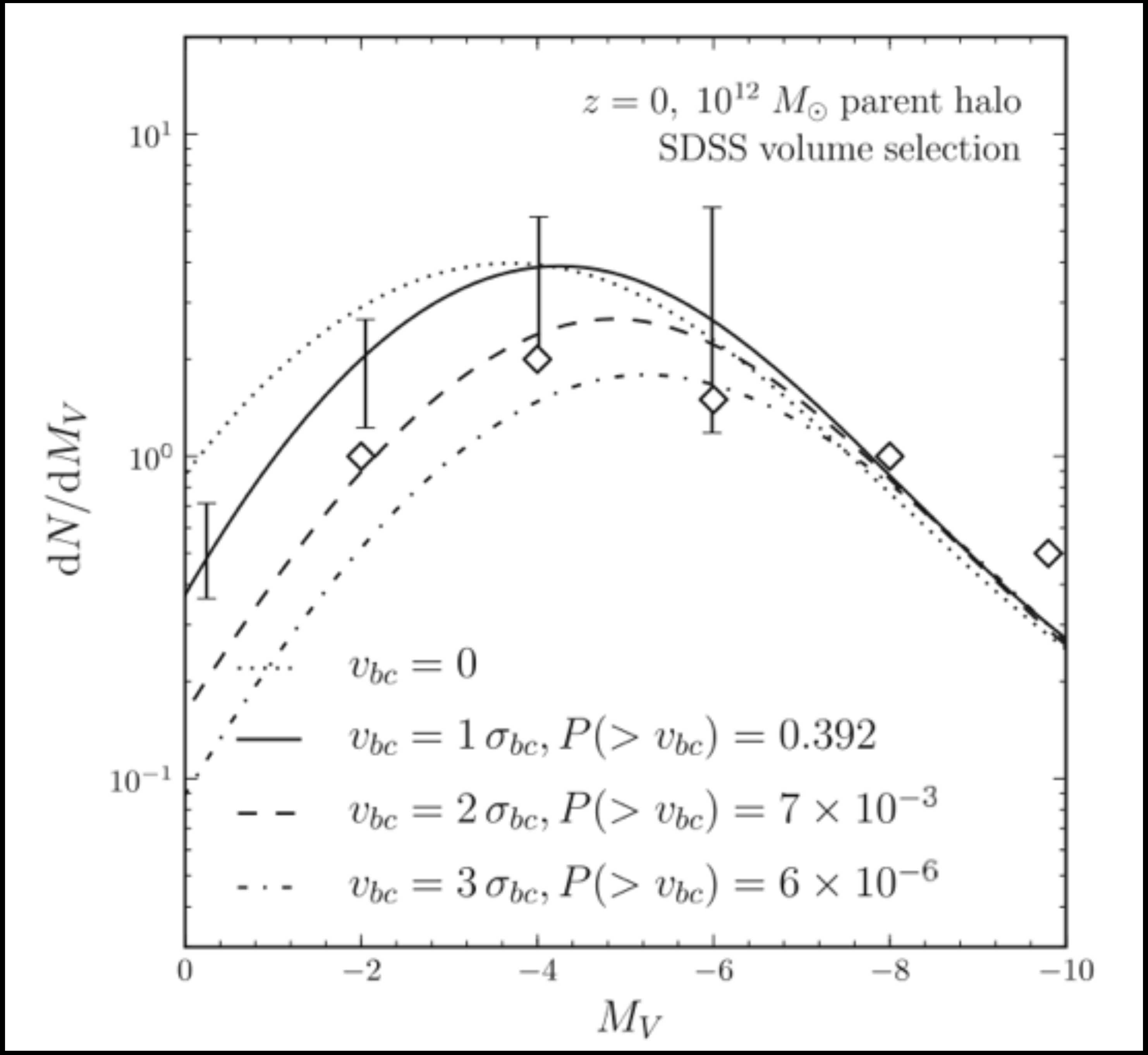


A wind can really sink galaxy formation!

Relative velocity is sourced by overdensities and so varies over different patches of Universe.
1 sigma = 10% of typical circular velocity for 10^6 Msun halos at z = 50

A MODEST PROPOSAL *(Not my own)*

Bovy & Dvorkin 13: RV could suppress low-mass halos before reionization



Diamonds = data from Koposov+09

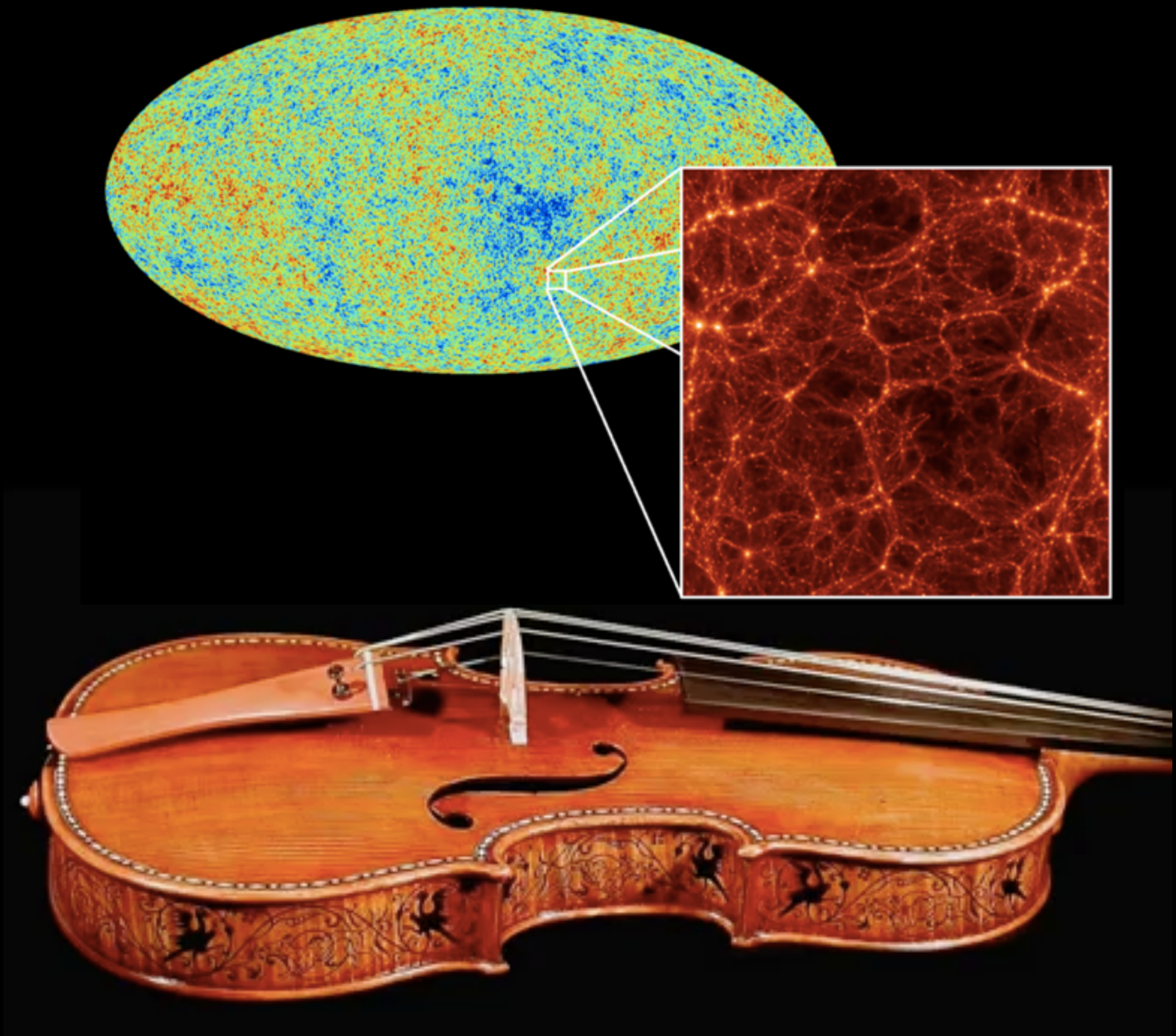
SO WHAT DO WE NEED?

A 1.5 to 2.5 sigma above-average baryon-CDM relative velocity in the Milky Way

For the Milky Way, we can in fact simply go ahead and measure it.

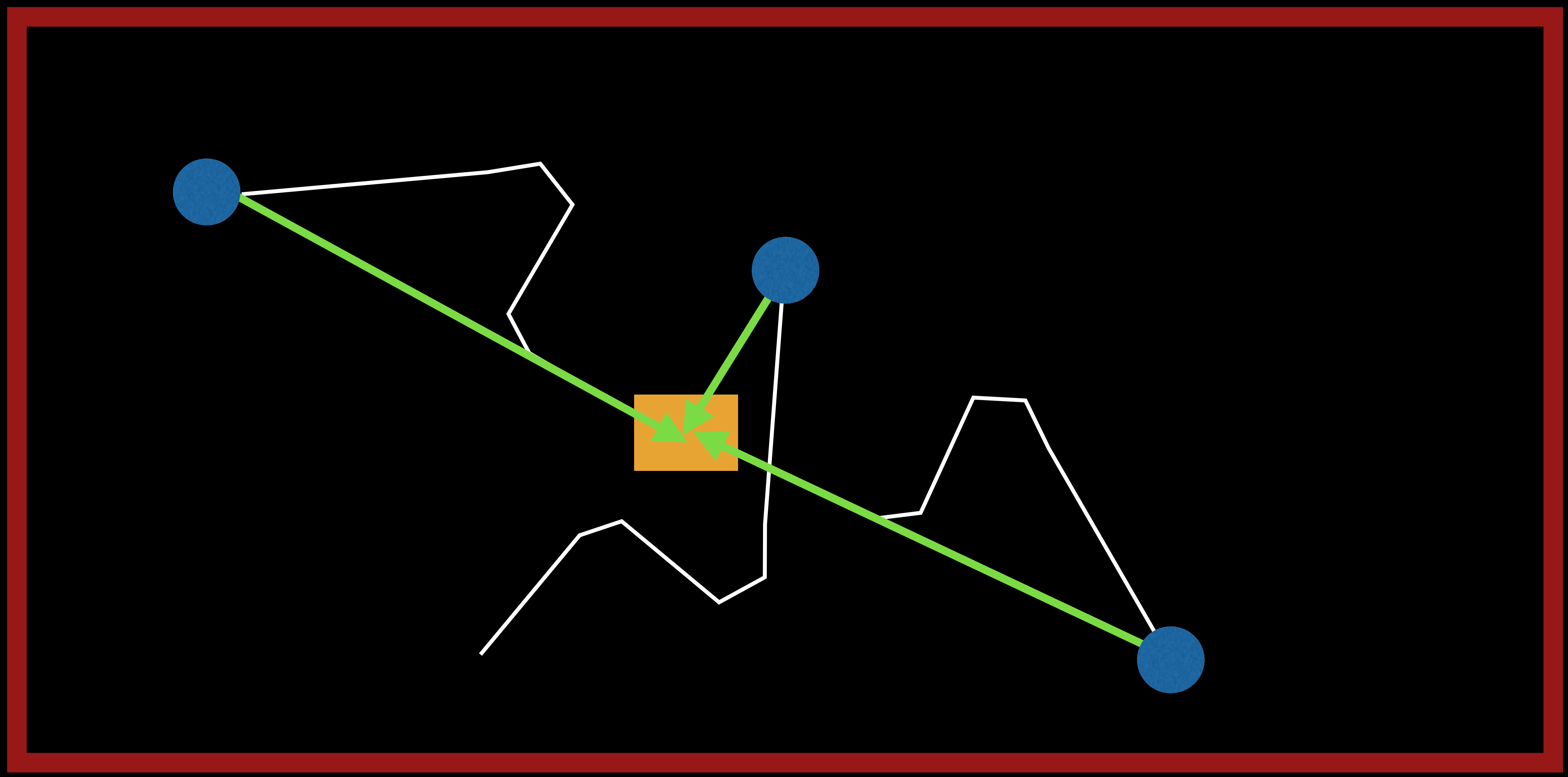
We have the Green's function.
We have the galaxy density field around us.

IMAGINE THE UNIVERSE A VIOLIN



A SINGLE PLUCK LAUNCHES A SINGLE WAVE

Each galaxy around the Milky Way is like a single pluck



Direction is always along separation from external galaxy to MW

Magnitude is set by Green's function (crudely drawn)

2MASS REDSHIFT SURVEY

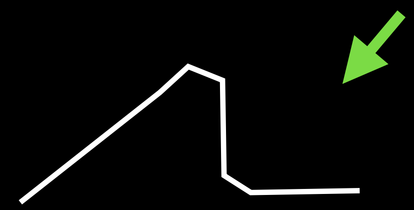
91% sky coverage, ~45,000 galaxies, ~98% complete, magnitude limit of K_s =11.75 mag, census of galaxies within local 300 Mpc

Recall Green's function only is non-zero up to 150 Mpc. Unlike traditional velocity reconstruction (sorry POTENT!), we have a tractable problem.

We create a volume-limited sample (~15,000 galaxies) so that we can ignore bias evolution: bias will be a constant.

Huchra+10, **ZS**, AS, MC,LG & DE17

$$\vec{v}_{bc}(0) = \int d^3\vec{r}\,\delta_{\rm lin}(\vec{r})v_G(r)\hat{r}$$



$$\delta_{\rm g}(\vec{r}) = b_1\delta_{\rm m}(\vec{r}) = b_1\left[\delta_{\rm lin}(\vec{r}) + \delta^{(2)}(\vec{r})\right]$$

$$\delta_{\rm lin}(\vec{r}) \approx \delta_{\rm g}(\vec{r})/b_1$$

Ignore non-linear evolution and ignore RSD.
We can test if these approximations are good using simulations, and we do (preliminary).

WHAT ABOUT BOUNDARY EFFECTS?

9% of sky is missing: does that matter? (we make azimuthally-symm. cuts)

Three methods:
1) Simulate

2) Throw randoms on full and cut sky and compute the change in relative velocity: ~7%

2) Model analytically: can impose an azimuthally -symmetric cut and solve for the change in variance: ~4%

$$\sigma^2_{\mathrm{bc,full\ sky}} = \int \frac{k^2 dk}{2\pi^2} P(k) \tilde{v}_G^2(k)$$

$$\sigma^2_{\mathrm{bc,azi.\ cut}} = 2\int \frac{k^2 dk}{2\pi^2} P(k) \sum_L (2L+1) \left(\tilde{v}_G^{[L]}(k)\right)^2 \times \sum_J \eta_J^2(0,\mu_{\mathrm{crit}}) \begin{pmatrix} L & 1 & J \\ 0 & 0 & 0 \end{pmatrix}^2$$

WHAT DO WE GET?

Assuming galaxy bias ~2, our preliminary result is 2.25 sigma.

I.e., enough for the Bovy & Dvorkin picture to work and, by itself, solve the missing satellite problem.

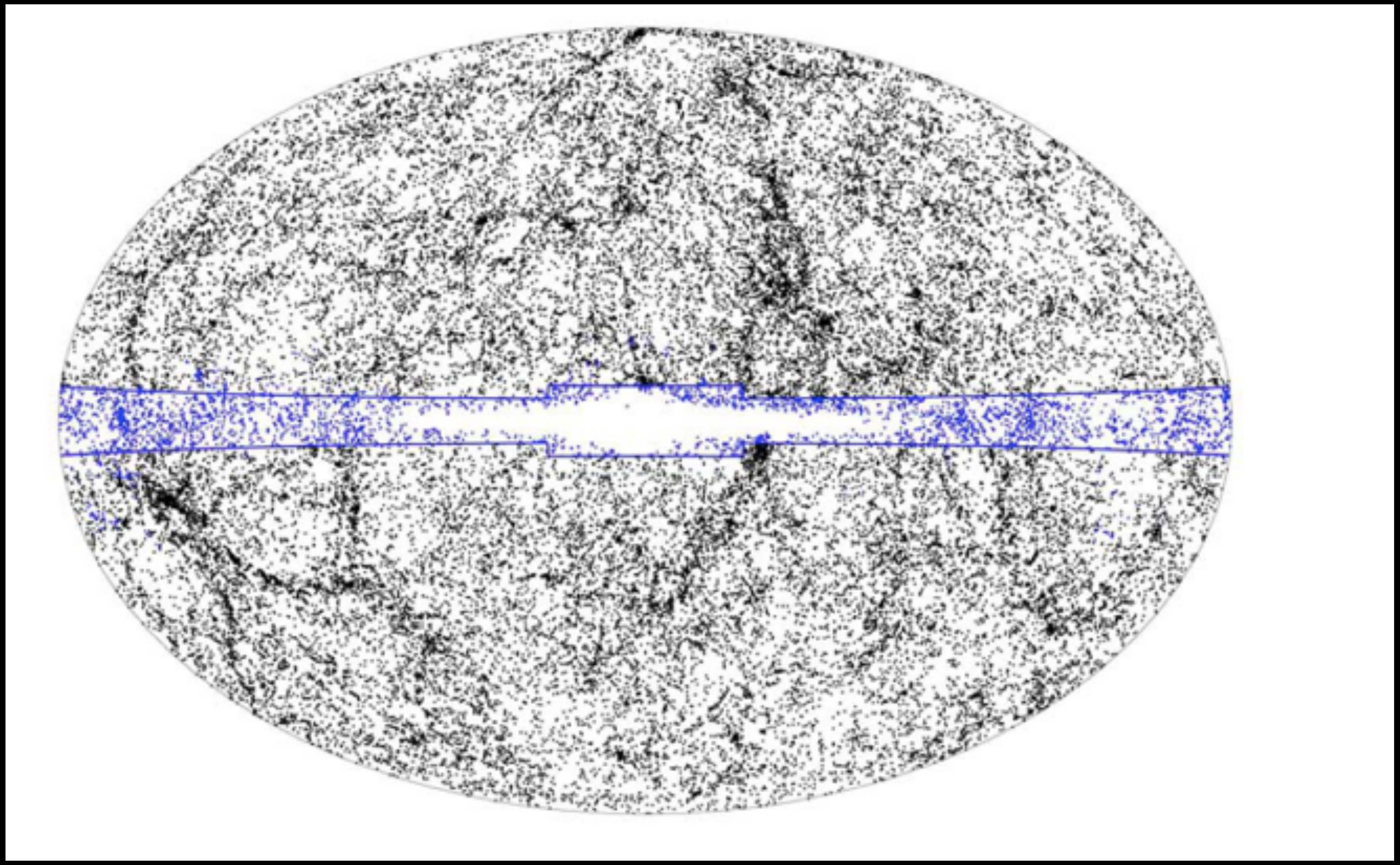
There are caveats, so we are doing further testing with simulations.

Hope I haven't "boared" you, and thanks to the organizers!

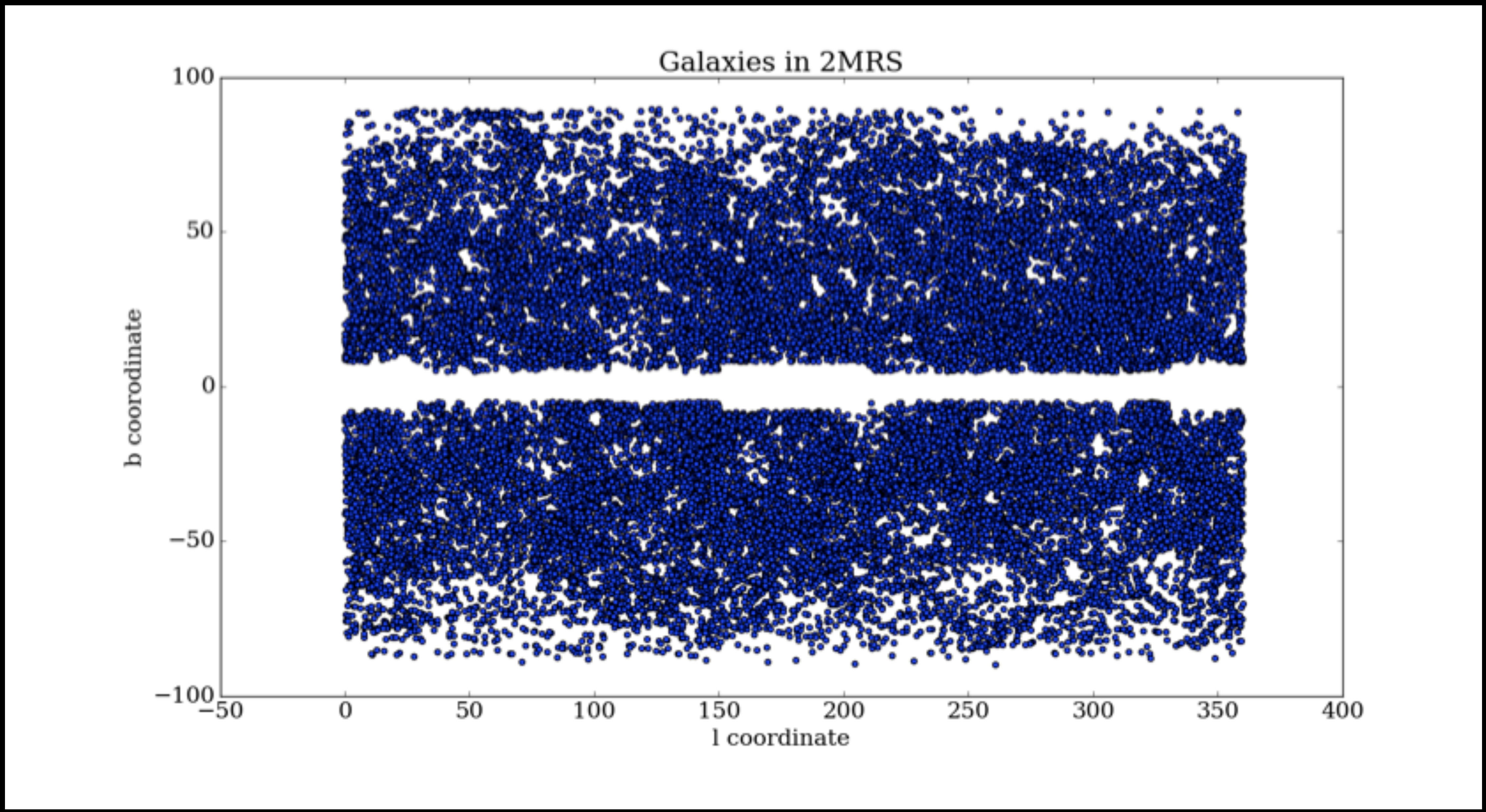
TABLE 1
LARGE REDSHIFT SURVEYS OF THE NEARBY UNIVERSE TO DATE

Survey	Sky coverage % 4π sr	Depth[a] (z)	Selection (band, flux)	# gals. ($\times 10^3$)	Reference
CfA1	30%	0.03	B=14.5 mag	2.4	de Lapparent et al. (1986)
ORS	60%	0.03	B=14.0 mag	8.5	Santiago et al. (1995)
SSRS2+ CfA2	60%	0.04	B=15.5 mag	23.6	da Costa et al. (1998a) & Huchra et al. (1999a)
IRAS PSCz	85%	0.08	60μm=0.6 Jy	16.1	Saunders et al. (2000a)
LCRS	1%	0.17	R=17.5 mag	25.3	Shectman et al. (1996)
2dF	8%	0.19	b_J=19.5 mag	245.6	Colless et al. (2001)
SDSS[b]	35%	0.33	r=17.5 mag	943.6	Aihara et al. (2011)
6dFGS	40%	0.10	K_s=12.65 mag	124.6	Jones et al. (2004, 2005, 2009)
2MRS11.25	83%	0.04	K_s=11.25 mag	20.6	Huchra et al. (2005)
2MRS	91%	0.05	K_s=11.75 mag	43.5	**this work**

NOTE. — (a): 90%-ile redshift value in catalog. (b): DR8 main galaxy sample.



Huchra+10



ZS, AS, MC, LG&DE17

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l_{1} & l_2 & l_3\\
m_1 & m_2 & m_3
\end{array}\right)
a_{l_1m_1}(r_1)a_{l_2m_2}(r_2)a_{l_3m_3}(r_3)

\vec{v}_{bc}(0) = \int d^3\vec{r}\; \delta_{\rm lin}(\vec{r}) v_G(r)\hat{r}
\delta_{\rm g}(\vec{r}) = b_1 \delta_{\rm m}(\vec{r}) = b_1\left[\delta_{\rm lin}(\vec{r}) + \delta^{(2)}(\vec{r}) \right]

\delta_{\rm lin}(\vec{r})\approx \delta_{\rm g}(\vec{r})/b_1
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