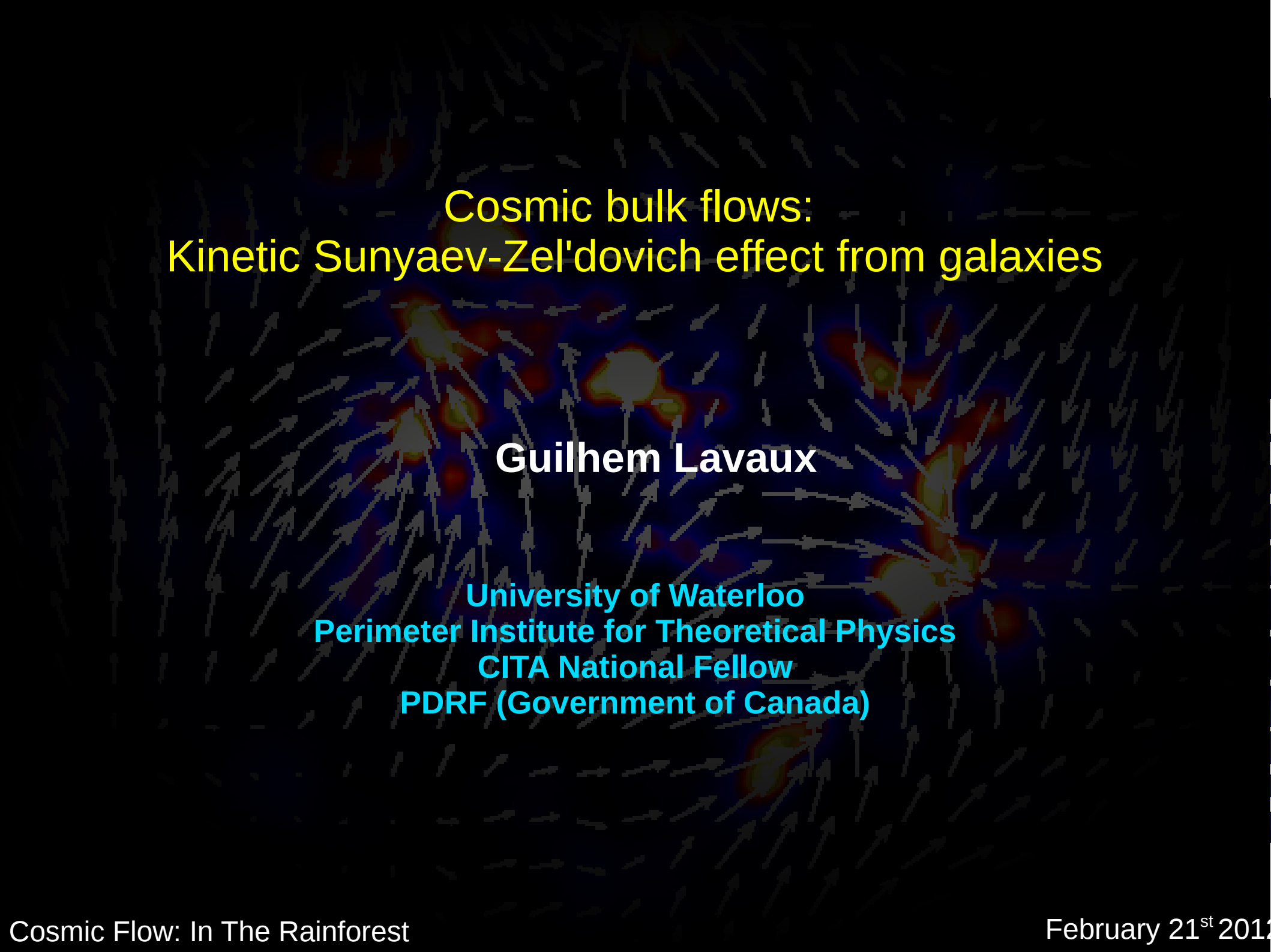
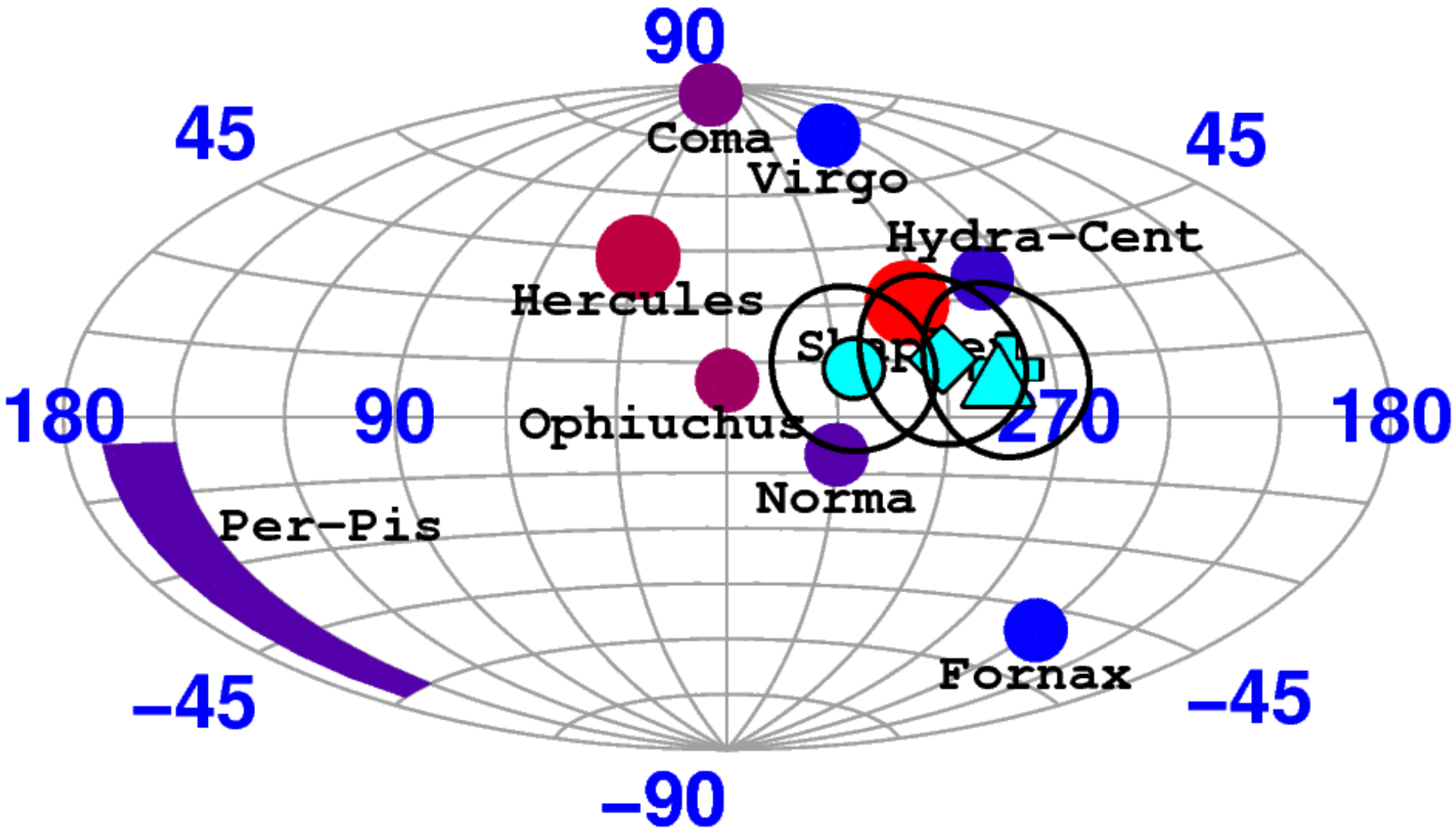


Cosmic bulk flows:
Kinetic Sunyaev-Zel'dovich effect from galaxies

Guilhem Lavaux

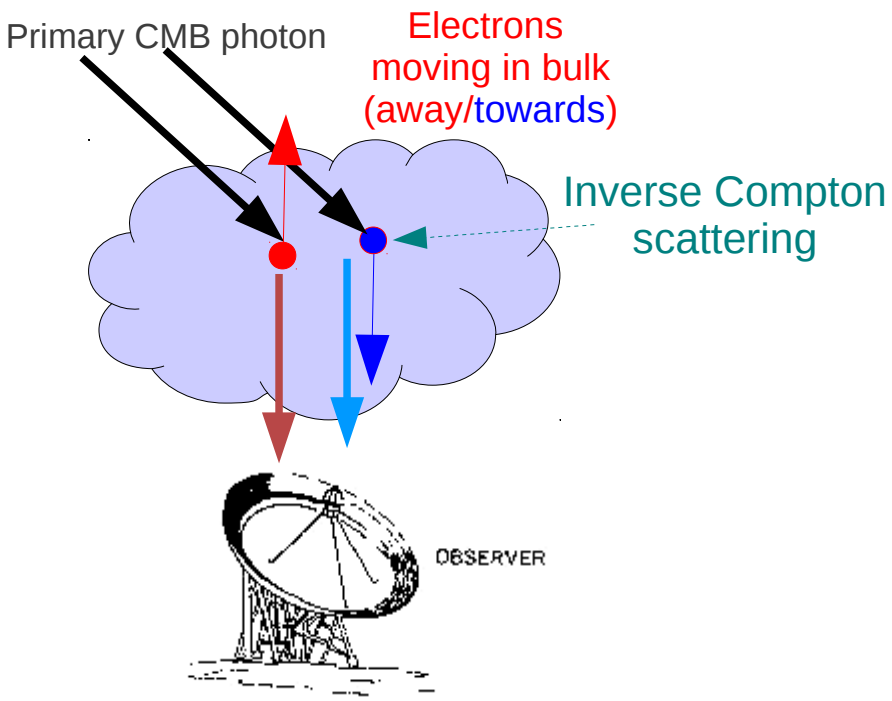
University of Waterloo
Perimeter Institute for Theoretical Physics
CITA National Fellow
PDRF (Government of Canada)

Bulk flow at 100 Mpc/h



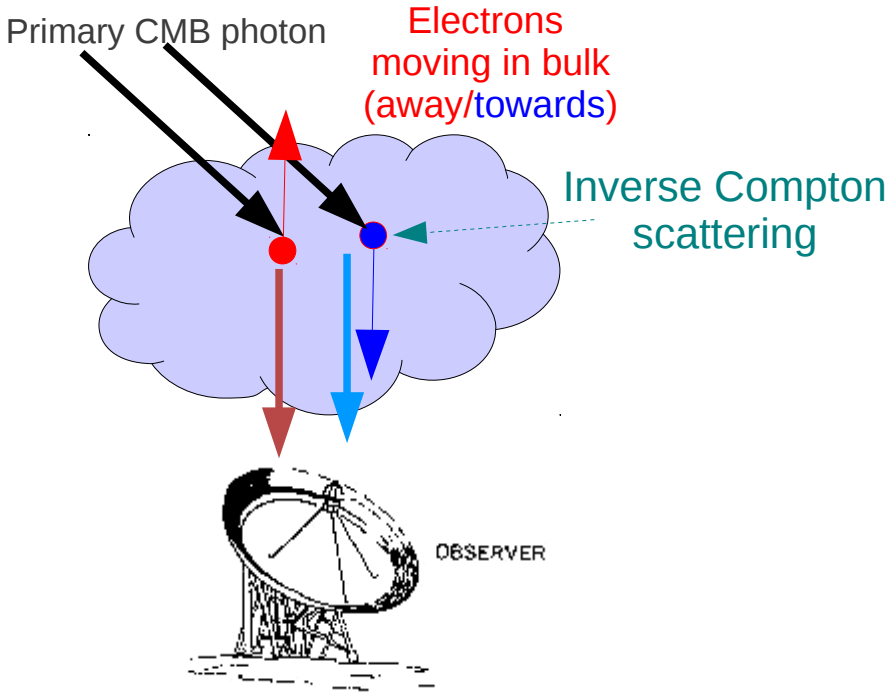
Kashlinsky et al. (300 Mpc/h)	l~283, b~12	|V| ~ 800 km/s
Watkins et al. (100 Mpc/h)	l~286, b~8	|V| ~ 407 km/s
Lavaux et al. (100 Mpc/h)	l~325, b~13	|V| ~ 480 km/s
Pike & Hudson (65 Mpc/h)	l~300, b~15	|V| ~ 271 km/s

Observing peculiar velocities: KSZ

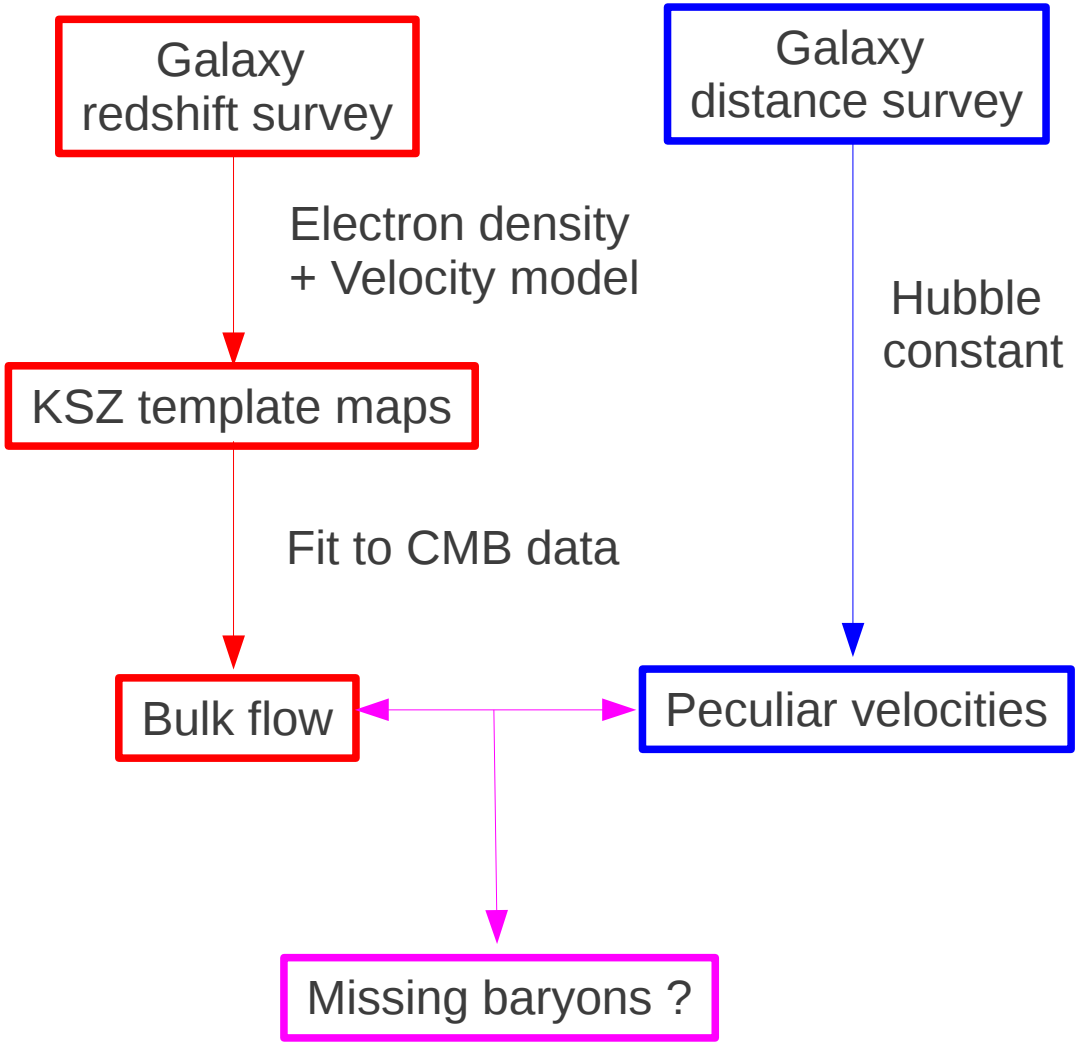


Kinetic
Sunyaev-Zel'dovich
(KSZ)

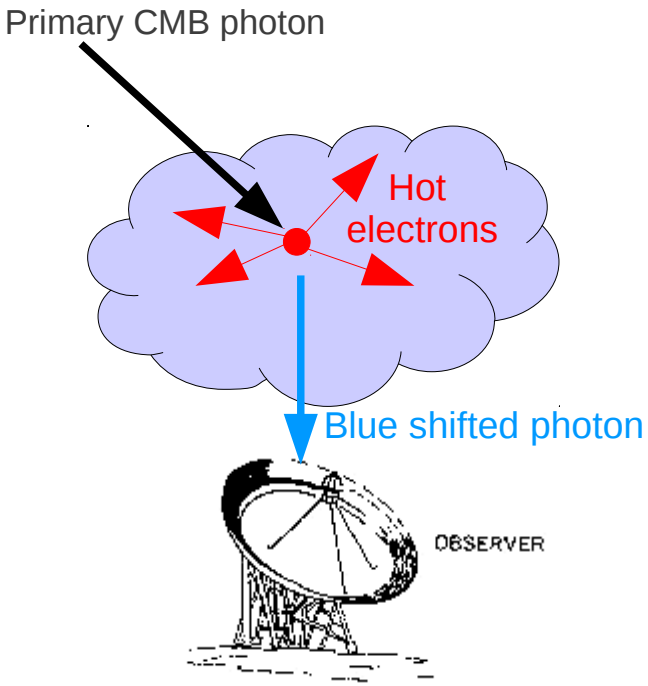
Observing peculiar velocities: KSZ



Kinetic
Sunyaev-Zel'dovich
(KSZ)



Signal vs. Datasets

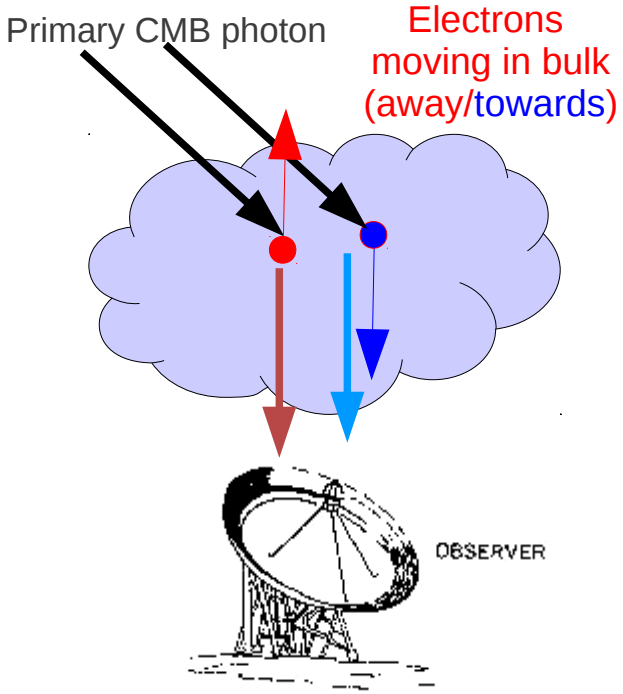


Thermal Sunyaev-Zel'dovich (TSZ)

$$\sim n_{\text{electrons}}\, T_{\text{electrons}}$$

Clusters

RBC catalog (Reflex, eBCS, CIZA) (Kocevski & Ebeling, 2006, ApJ)

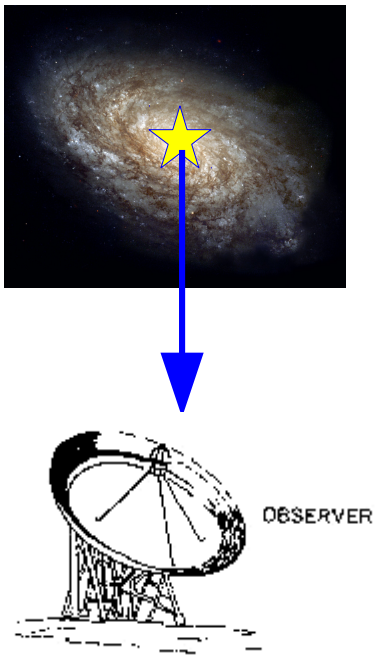


Kinetic Sunyaev-Zel'dovich (KSZ)

$$\sim n_{\text{electrons}}\, V_{\text{bulk, l.o.s.}}$$

Galaxies

2M++ galaxy compilation (Lavaux & Hudson 2011)



Point sources contamination (PSC)

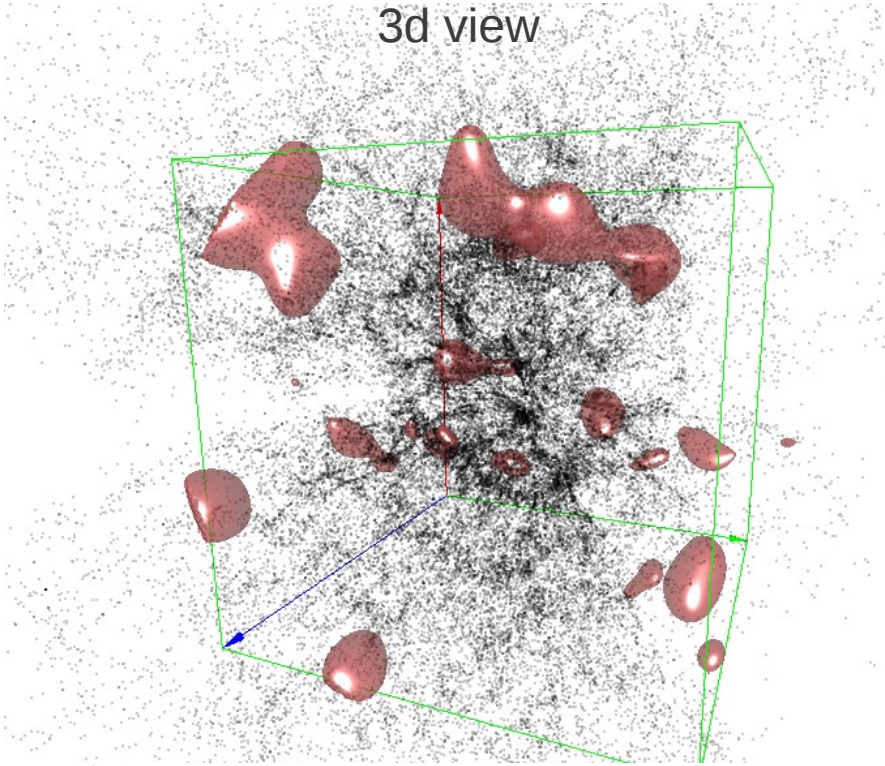
$$\sim n_{\text{galaxies}}$$

Galaxies

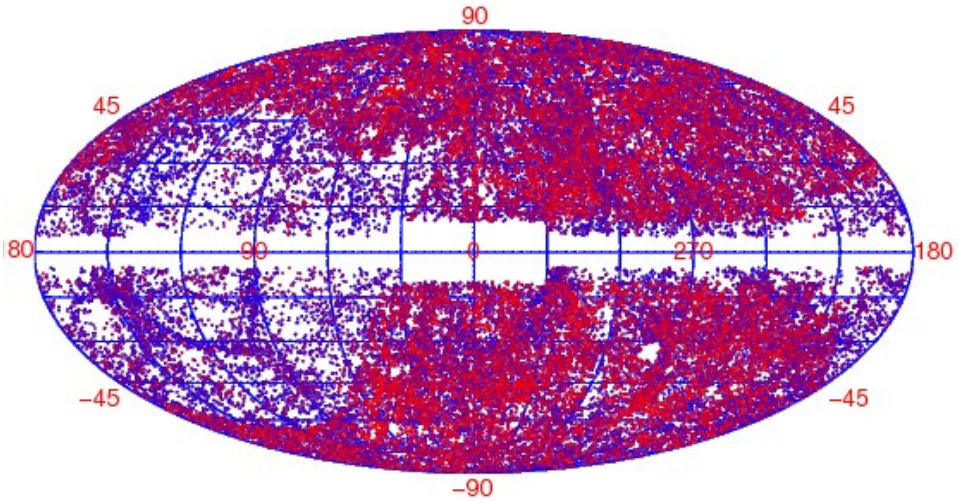
2MASS eXtended Source Catalog (Skrutskie & al., 2006)

The 2M++ galaxy redshift catalog

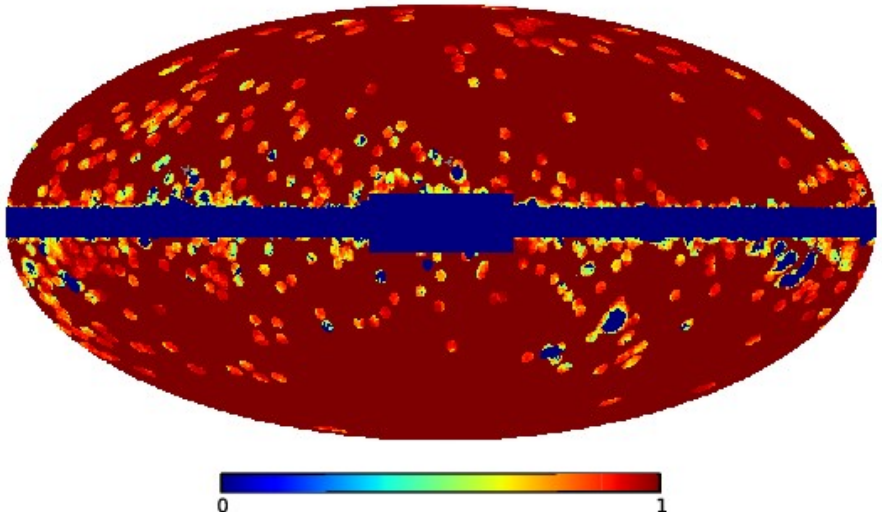
3d view



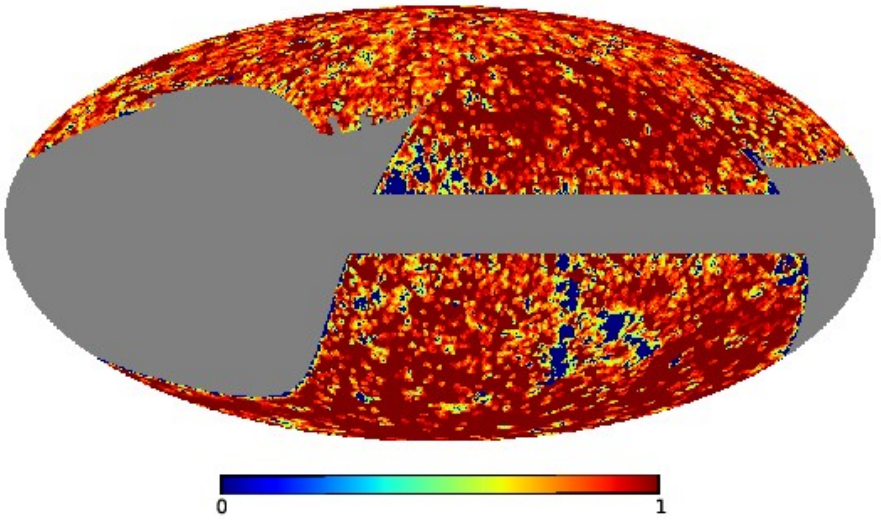
Galaxy distribution



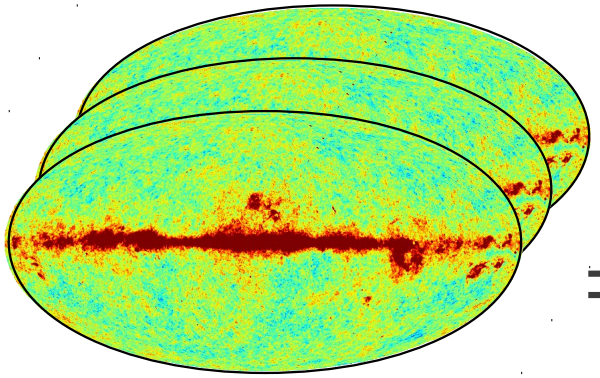
Completeness at K=11.5



Completeness at K=12.5

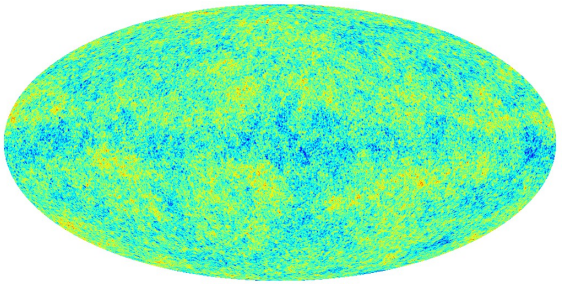


Model for 2.7K temperature



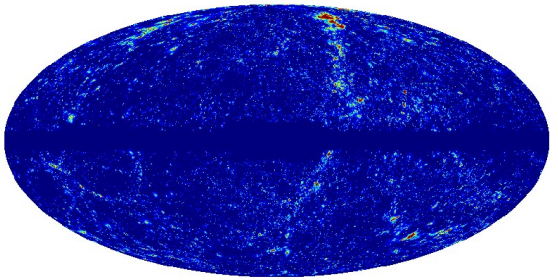
Sky
(different frequency channels)

= Beam (



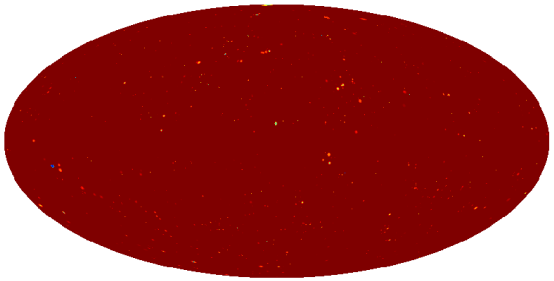
Primary CMB

+



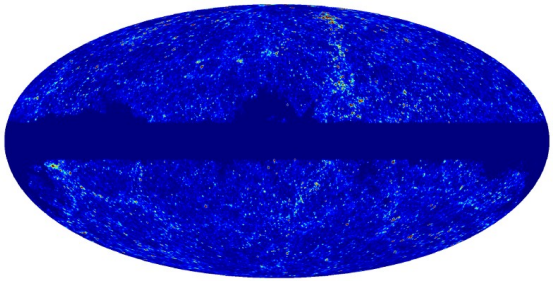
Kinetic
Sunyaev-Zel'dovich

+

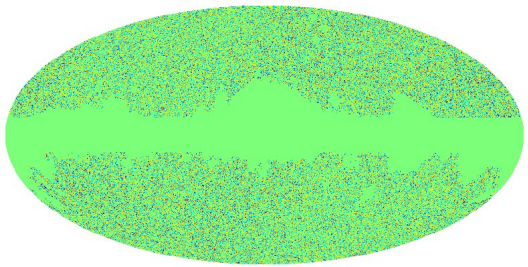


Thermal
Sunyaev-Zel'dovich

+



) +

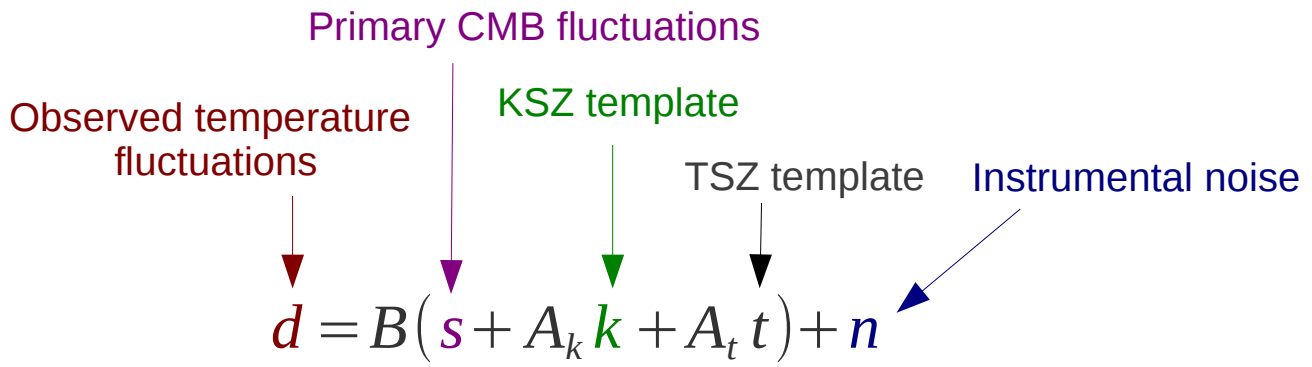


Instrumental noise

Lavaux, Hudson & Afshordi (2012, in prep.)

Model fitting

Simplified model



Statistics, marginalized over primary CMB:

$$\chi^2(A_k, A_t) = (d - A_k B k - A_t B t)^\dagger (B S B + N)^{-1} (d - A_k B k - A_t B t)$$

Analytical best fit

$$A_i = \sum_{j=1}^{2} C^{-1}_{i,j} m^\dagger_j D^{-1} d$$

$$C_{i,j} = m_i D^{-1} m_j$$

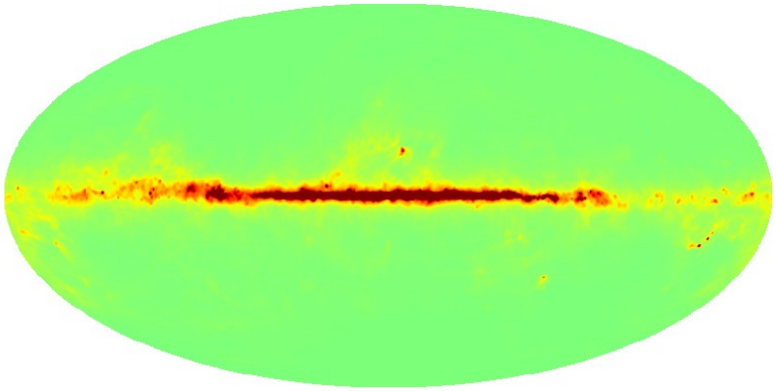
$$D = B S B + N$$

$$m_i = \begin{cases} \text{k} & i = 1 \\ \text{t} & i = 2 \end{cases}$$

Lavaux, Hudson & Afshordi (2012, in prep.)

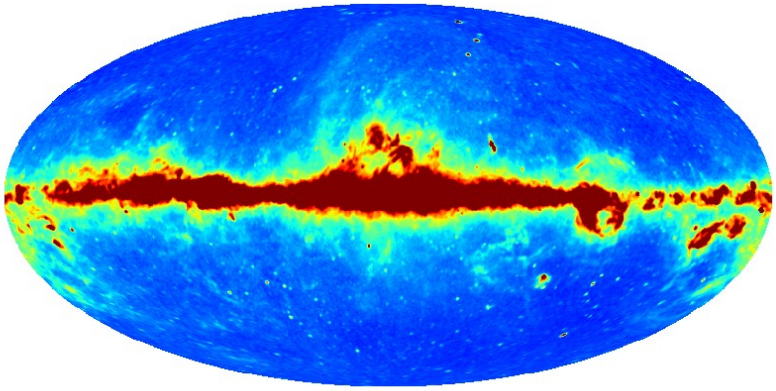
Model for the foreground

WMAP7 model of galactic foreground



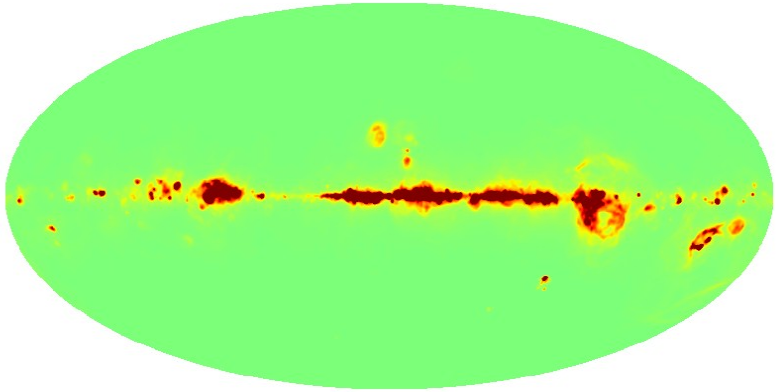
Dust emission

Schlegel & al (1998)
Finkbeiner & al (1999)



Synchrotron + Free-Free

WMAP7



Hα emission

Finkbeiner (2003)

Lavaux, Hudson & Afshordi (2012, in prep.)

Model for TSZ : cluster physics

Dark matter

NFW profile

Gravitational potential

Matter physics

Polytropic gas

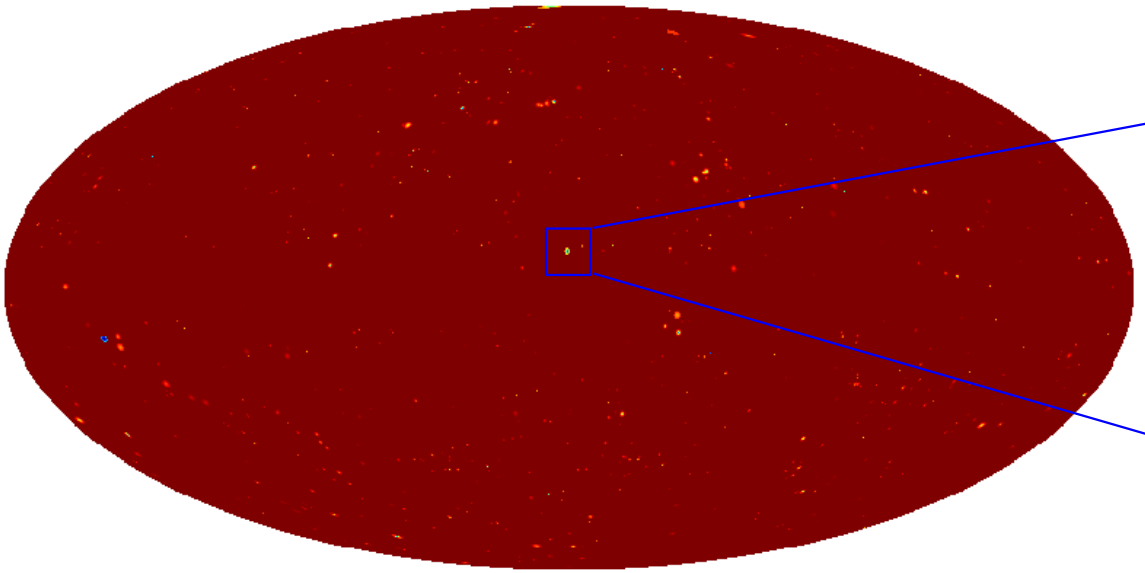
Accretion shock

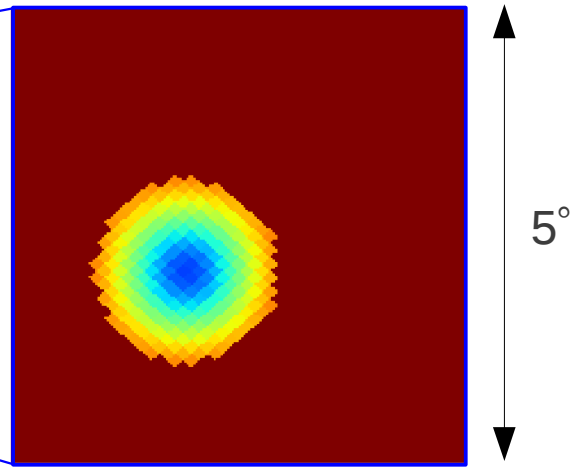
Gaz heating at R_{virial}

Gas and temperature profile
(Afshordi & al. 2005, ApJ)

Cluster data

RBC catalog
(Kocevski & Ebeling)



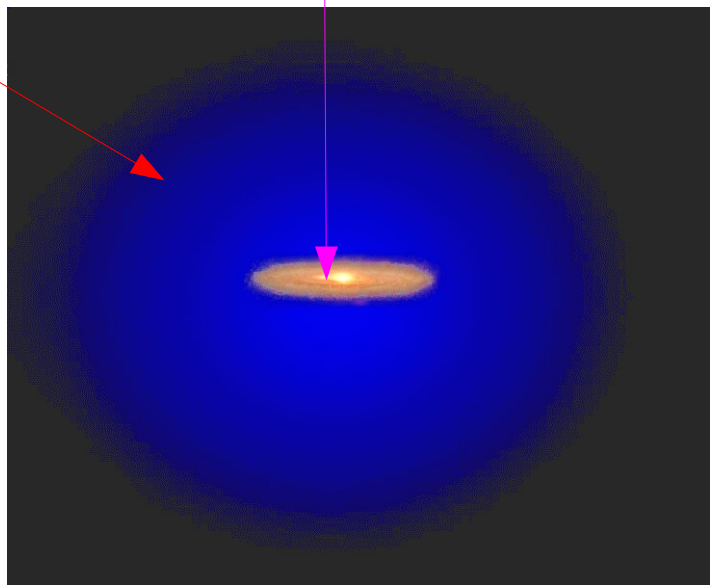


Lavaux, Hudson & Afshordi (2012, in prep.)

Model for KSZ : galaxies

Dark matter halo
+
plasma corona
(Fukugita & Peebles 2006)

Visible galaxy



Isothermal model for the halo:

$$\rho_g(r) = \frac{\Omega_b}{\Omega_m}\frac{\sigma^2}{2\pi G}\frac{1}{r^2} = \frac{\rho_0}{r^2}$$

$$\sigma \approx 160 \text{ km/s}$$

$$r_v \approx 220 \text{ kpc/h}$$

Fraction of free electrons

Integrated profile function

$$\Delta T_{KSZ}(\hat{n}) = -\frac{2 T_{CMB} \sigma_T f_e \rho_0}{\mu m_p c}\frac{1}{D_A} p\left(\frac{r_c}{R_V}\right)\vec{V}.\hat{n}$$

Number of charge / atom unit

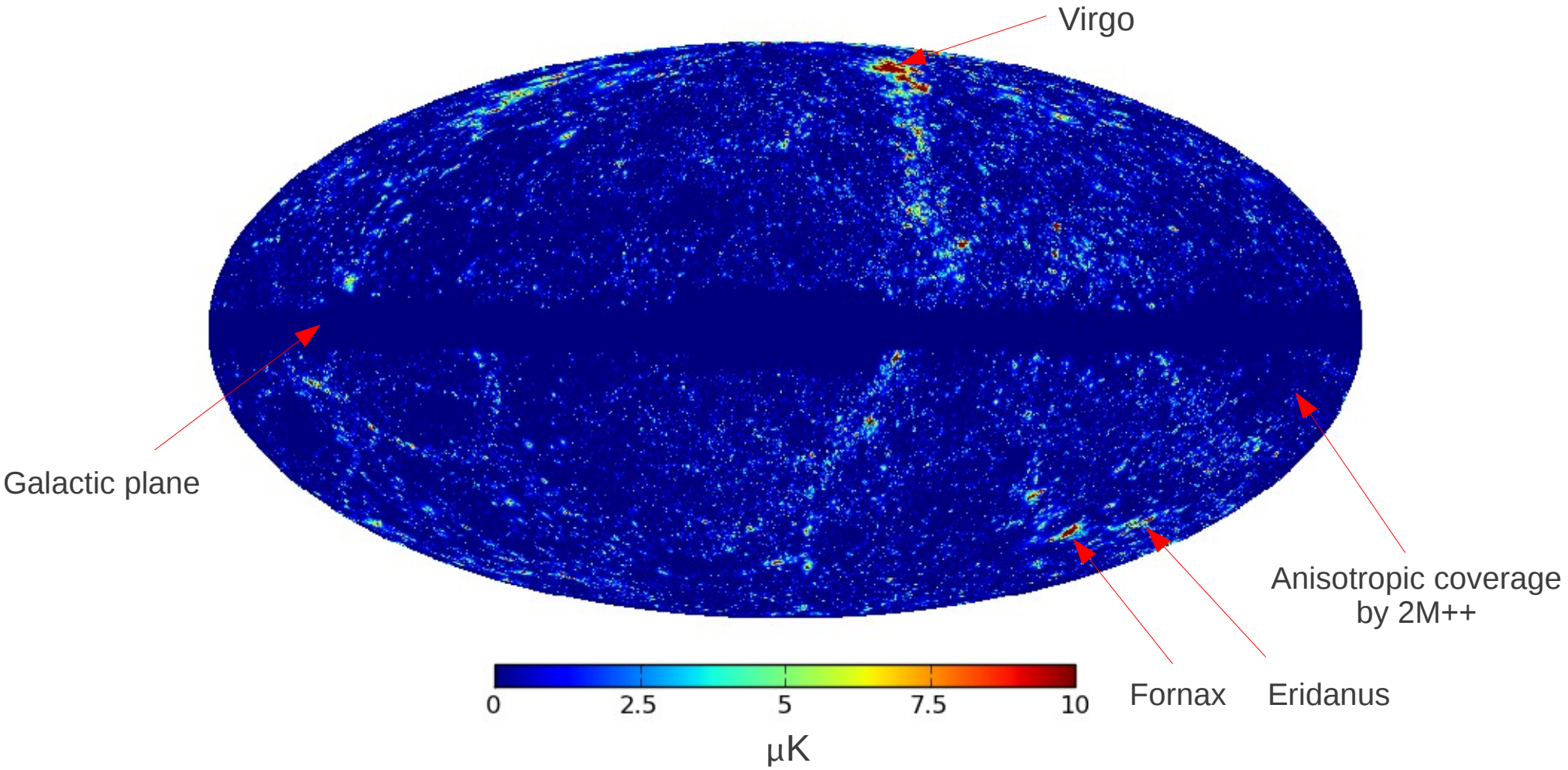
Angular distance

Galaxy velocity

Lavaux, Hudson & Afshordi (2012, in prep.)

Model for KSZ : sky template

Velocity modeled as a bulk flow: **unique** velocity vector



Map normalized to 100 km/s, no dipole weighing

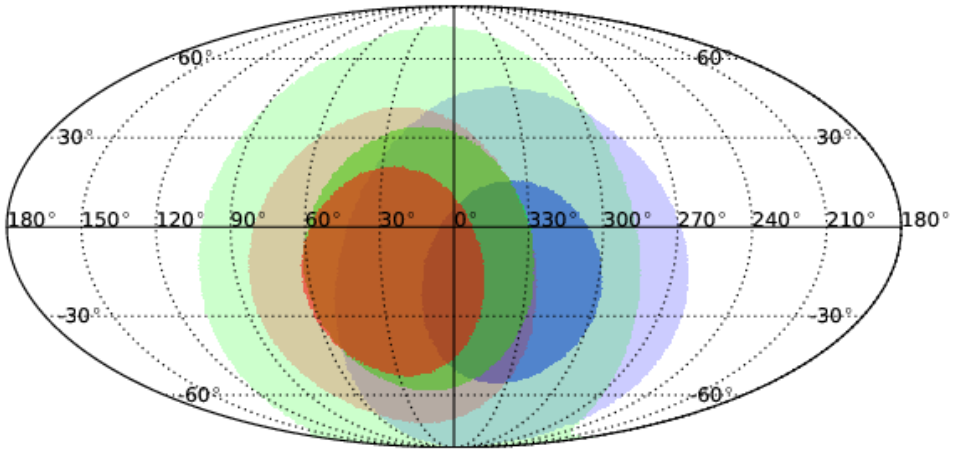
Depth limited to 200 Mpc/h

Results

Sky cut	KSZ depth (h^{-1} Mpc)	TSZ	KSZ (km s^{-1})		
			V_x	V_y	V_z
$\|b\| \geq 15°$	50	1.36 ± 0.12	534 ± 293	-225 ± 281	-176 ± 184
$\|b\| \geq 15°$	100	1.37 ± 0.11	333 ± 220	85 ± 217	-74 ± 143
$\|b\| \geq 15°$	200	1.37 ± 0.11	382 ± 203	180 ± 199	-121 ± 133

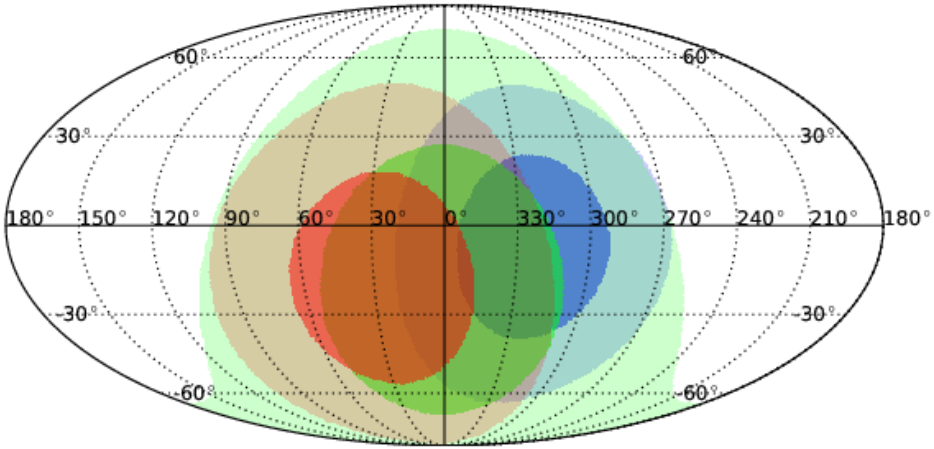
Decreasing error

TSZ not masked



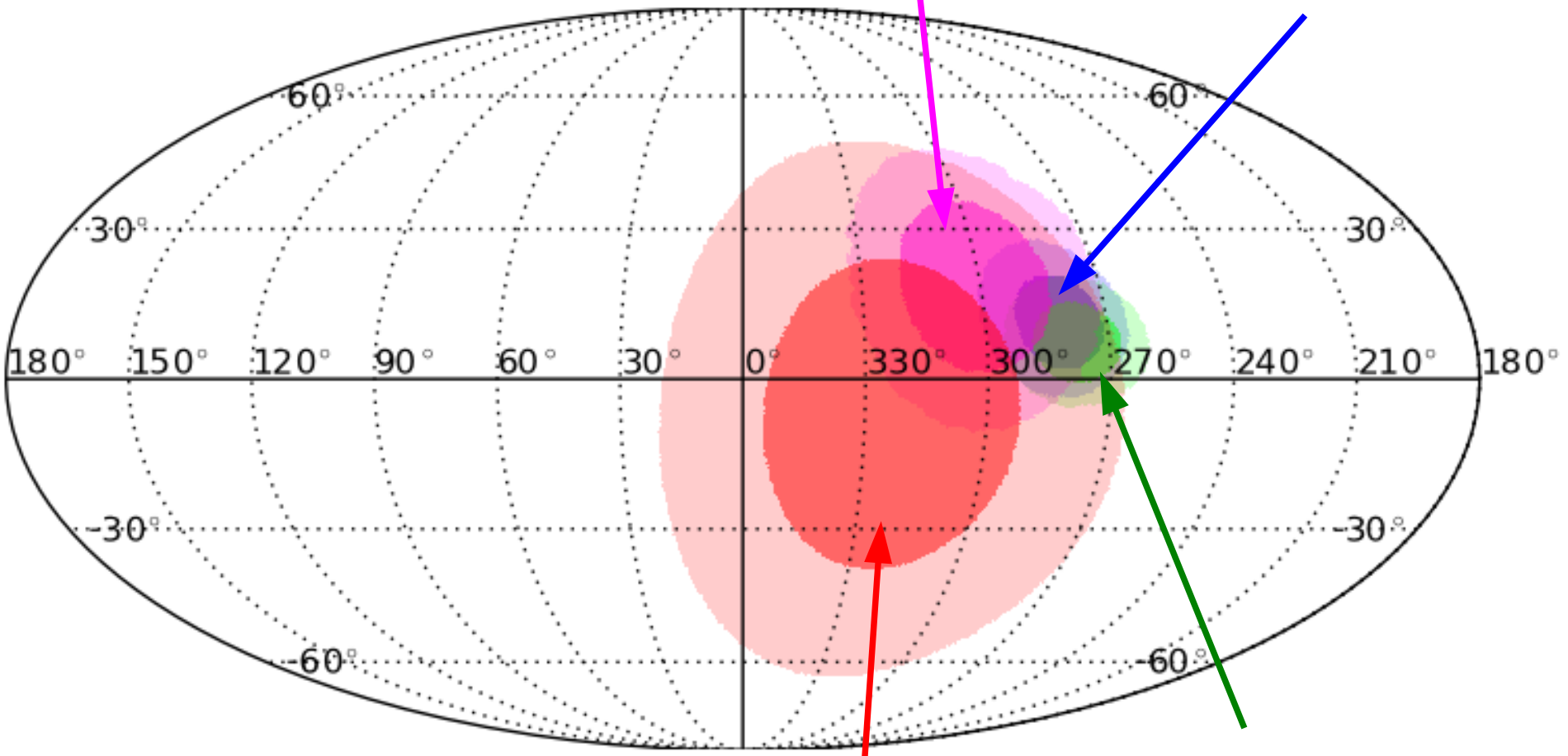
50 Mpc/h, **100 Mpc/h**, **200 Mpc/h**

TSZ masked



50 Mpc/h, **100 Mpc/h**, **200 Mpc/h**

Comparison with galaxy bulk flows



Ionized baryon fraction

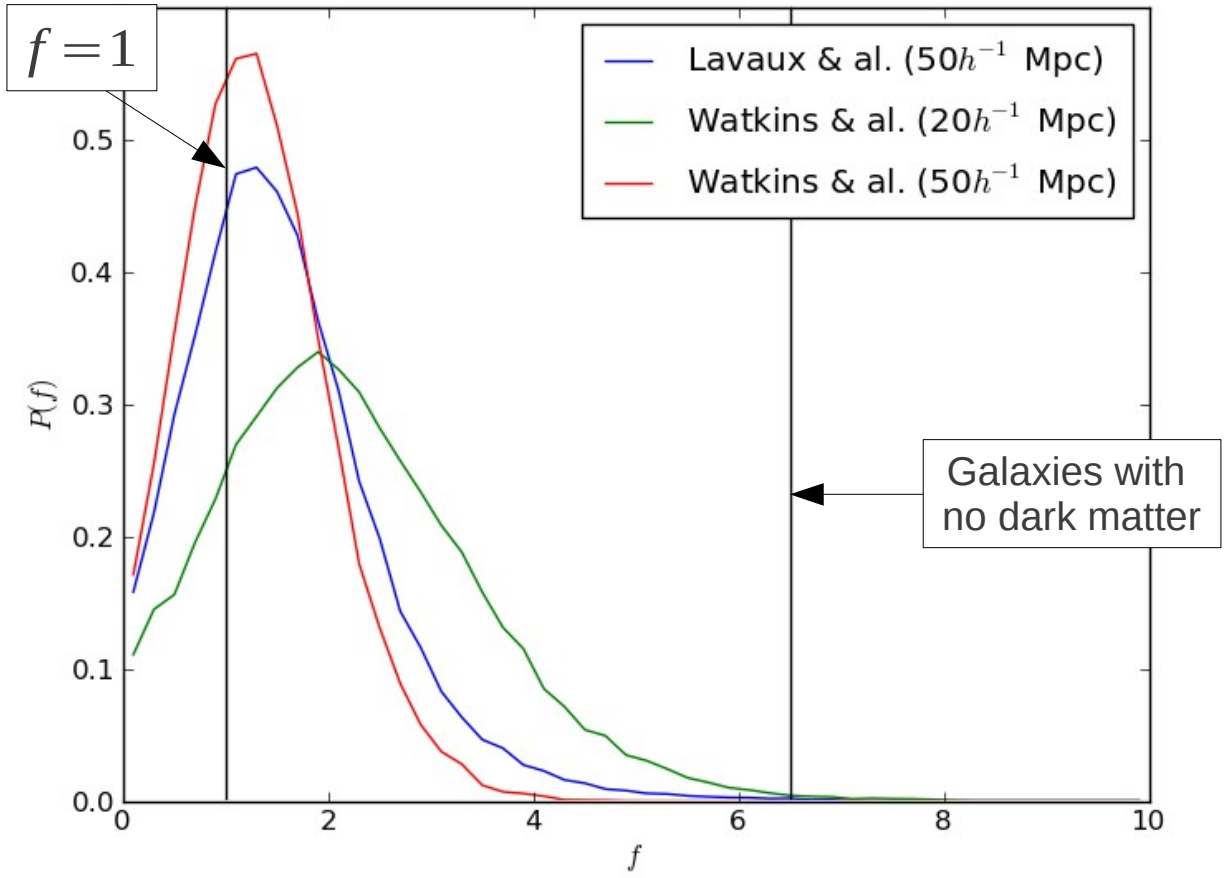
Reminder

$$\Delta T_{\mathrm{KSZ}}(\hat{n}) \propto f \vec{V}_{\mathrm{bulk}} . \hat{n} \quad \Rightarrow \quad f V_{\mathrm{bulk},i} = V_{0,i} \pm \sigma_{V_{0,i}}$$

Fraction of free electrons

Measured KSZ flow

$$\chi^2 = \sum_{i=1}^{3} \frac{\left(f V_{\mathrm{bulk},i} - V_{0,i}\right)^2}{f^2 \sigma^2_{\mathrm{bulk},i} + \sigma^2_{V_{0,}i}}$$



Ionized baryon fraction

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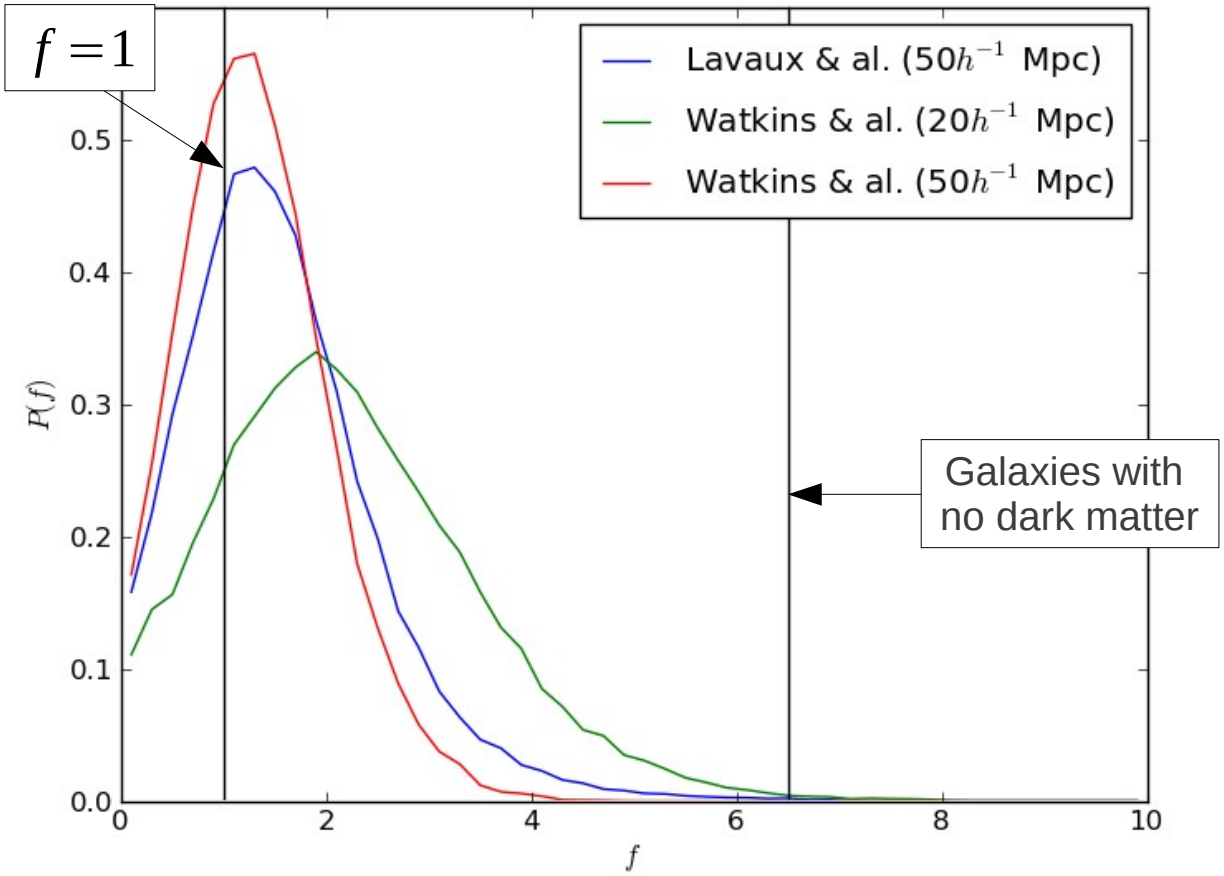

Summary/Limitations

- Normalization of the profile
- Fraction of free electrons
- Shape of the profile
- Direction normalization independent
- Cosmic variance effects
- Foregrounds