Investigating Anisotropies in the Cosmic Expansion with the Nearby Supernova Factory

24th Rencontres de Blois

Particle Physics and Cosmology

For the Nearby Supernova Factory

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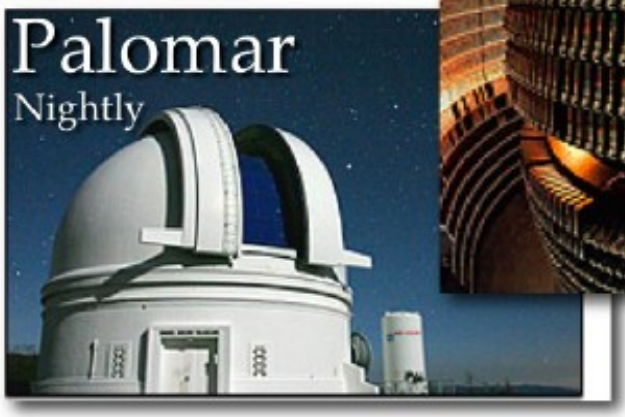
The Nearby SNfactory

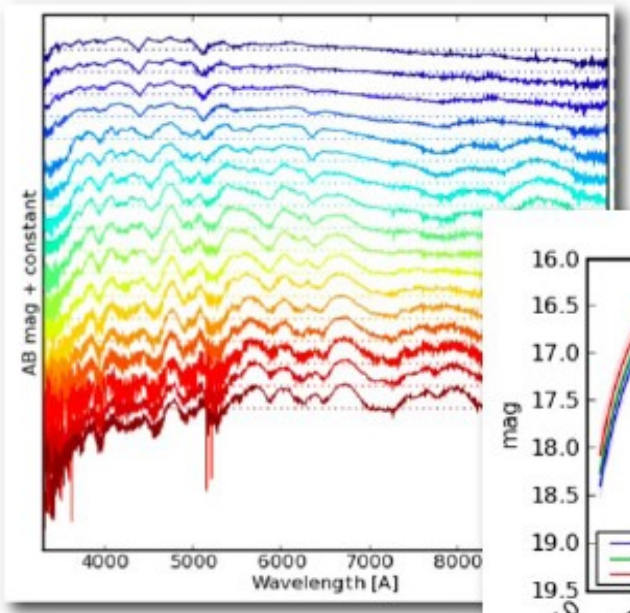
1. Discover

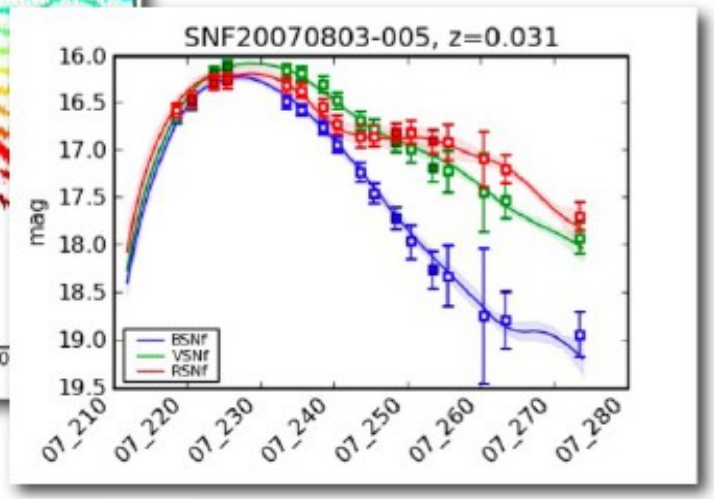


2. Observe

Custom, unique spectrometer designed for nearby SN obs

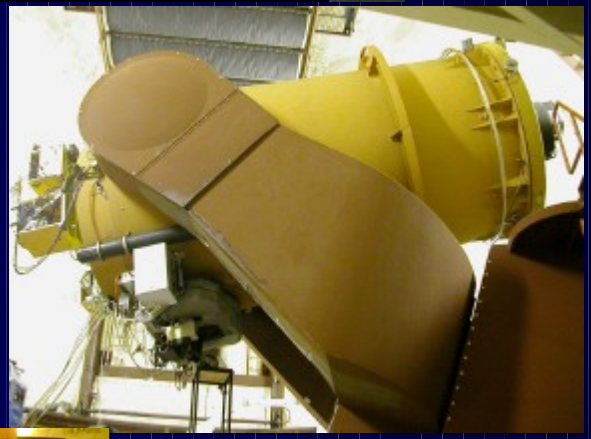
3. Analyze

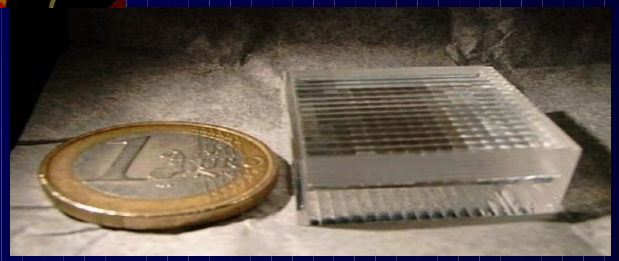


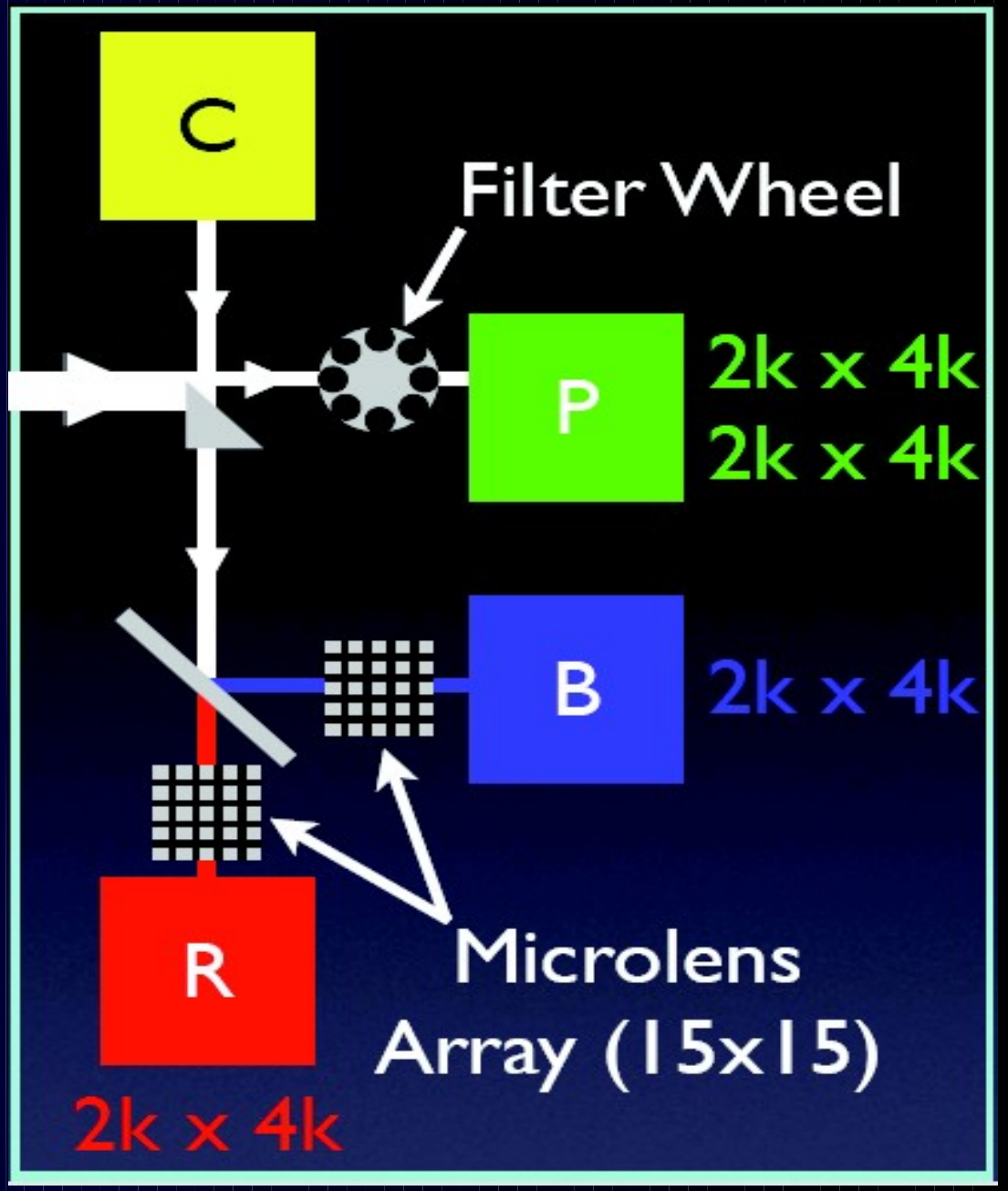


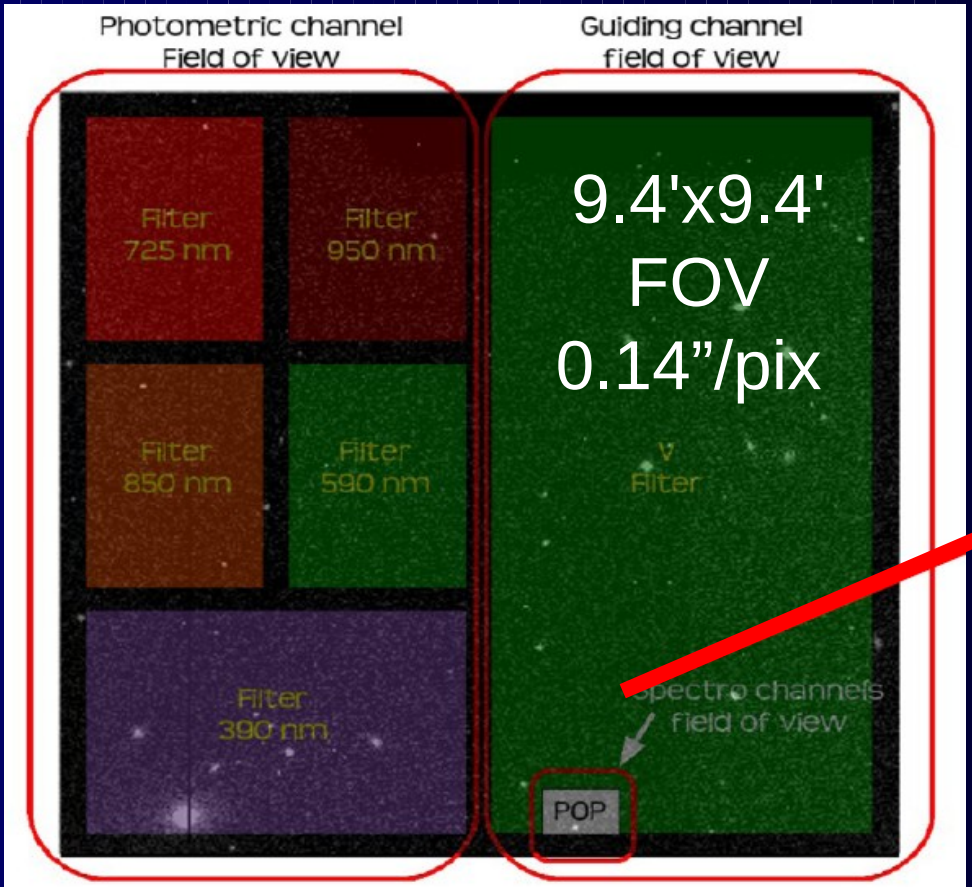
Stephen Bailey

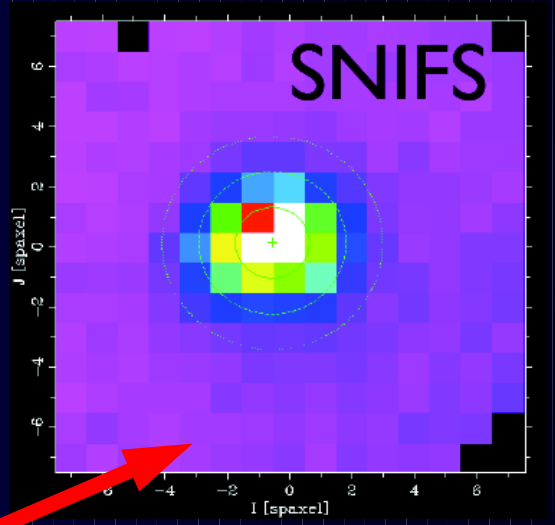
Supernova Integral Field Spectrograph (SNIFS)





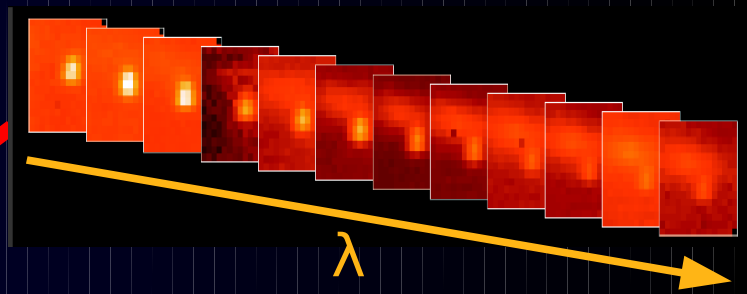




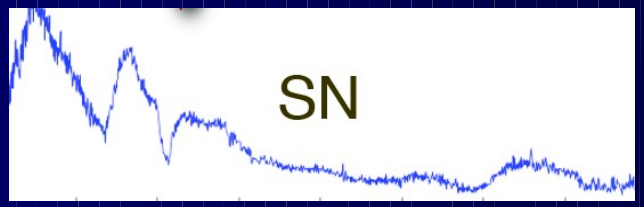


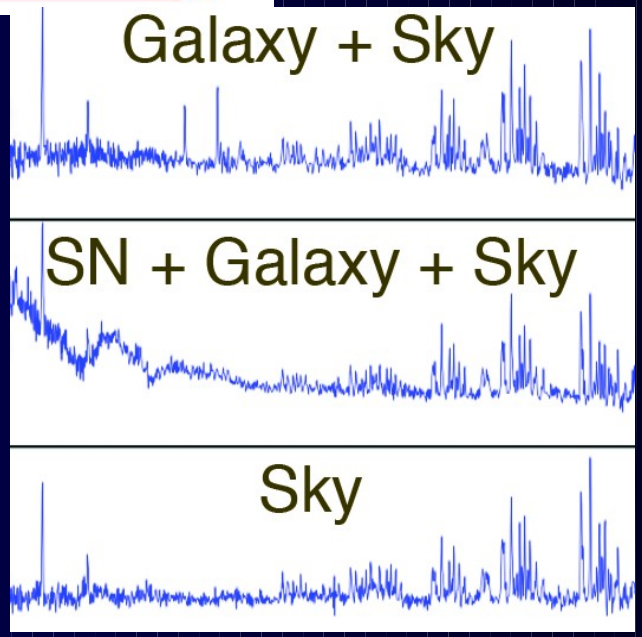
15x15 spaxels
=
225 spectra

6"x6" FOV
0.4"/spaxel

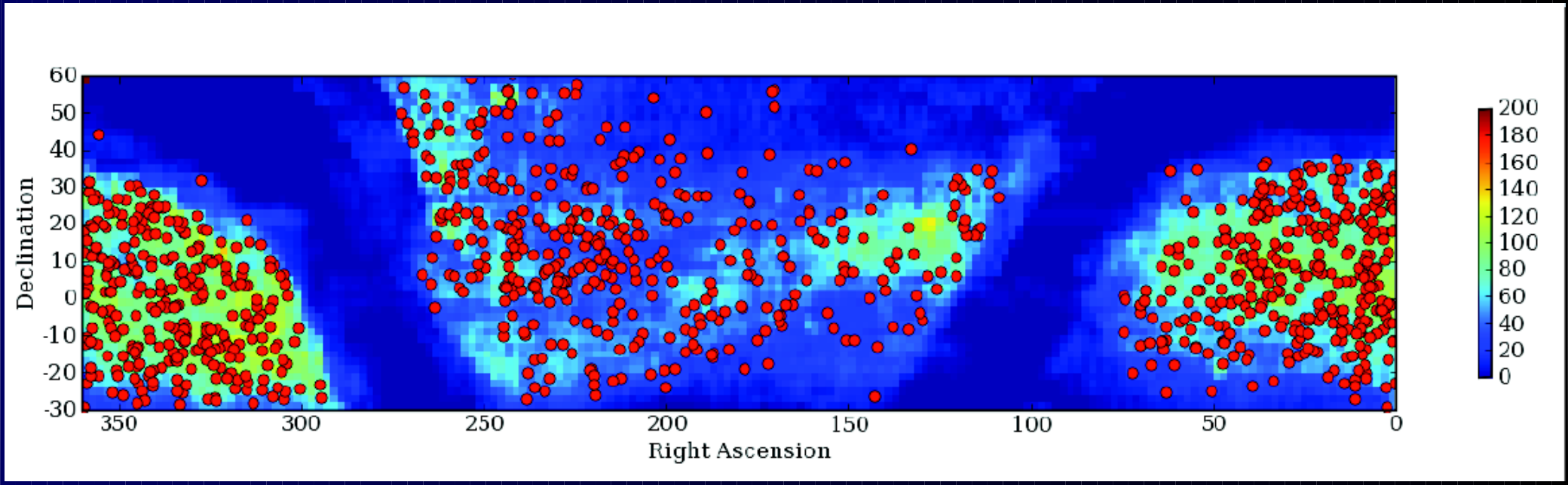


3D Datacube

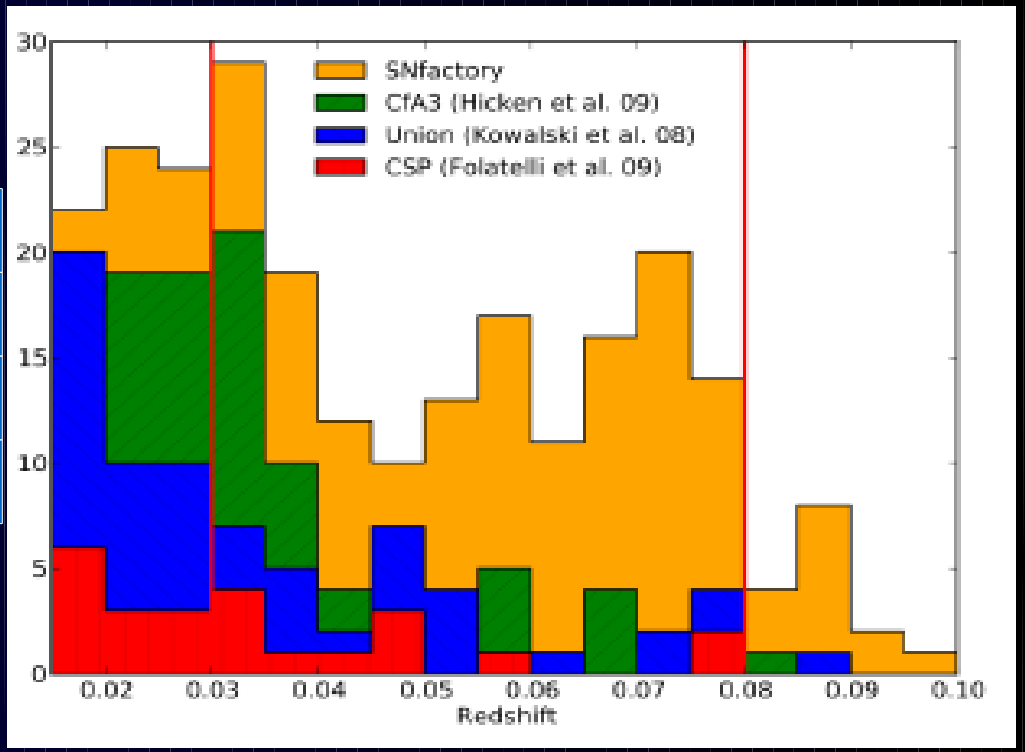




The SNF Dataset



	SNfactory	Others	Total
SN	~620	~70	~690
SN Ia	~400	~50	~450
Follow-up	~150	~40	~190



Contents

- The Nearby Supernova Factory
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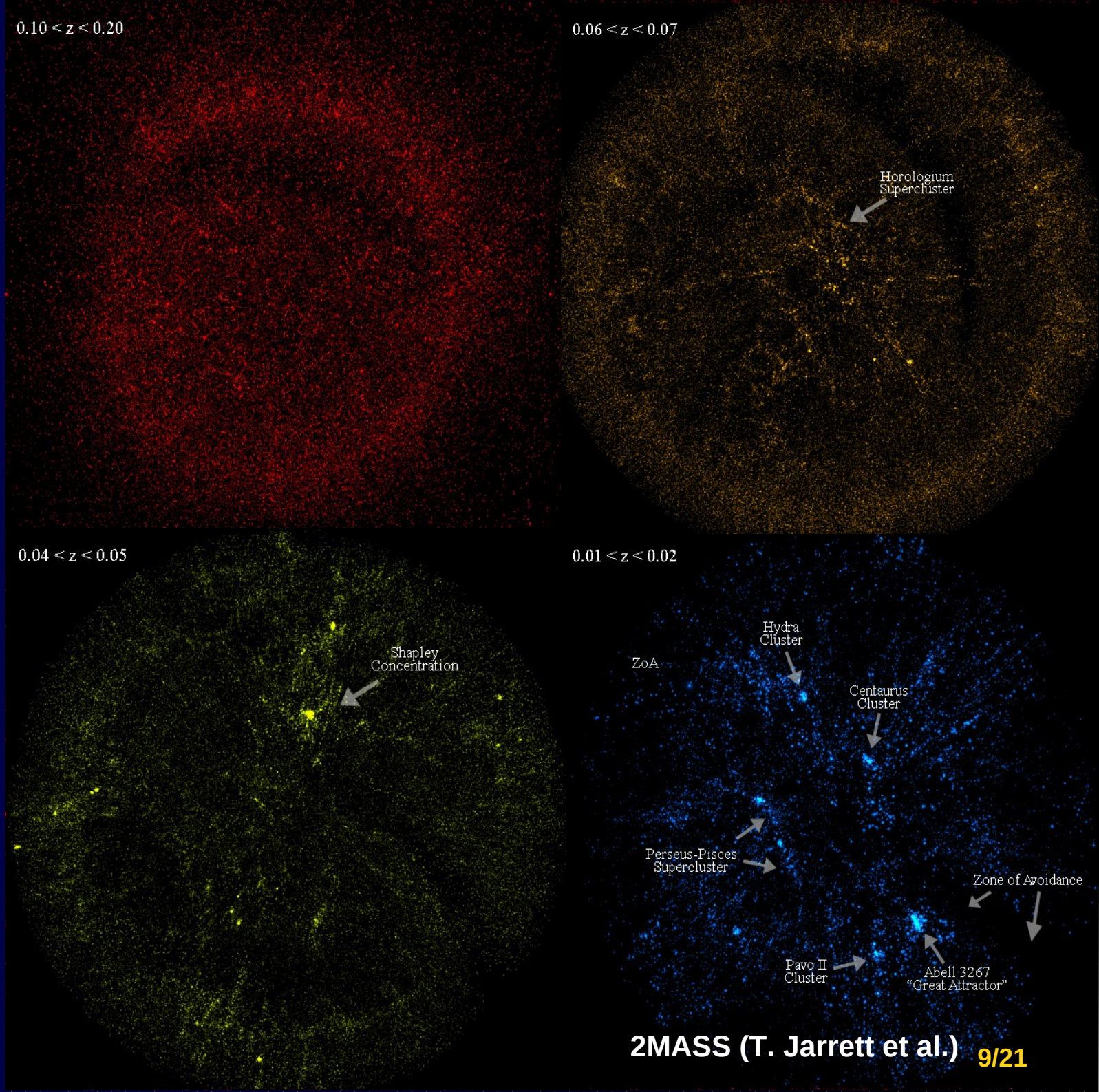
- On smaller scales (< 400 Mpc) the universe is neither homogeneous nor isotropic

- Structures and matter concentrations emerge, the Copernican principle becomes invalid

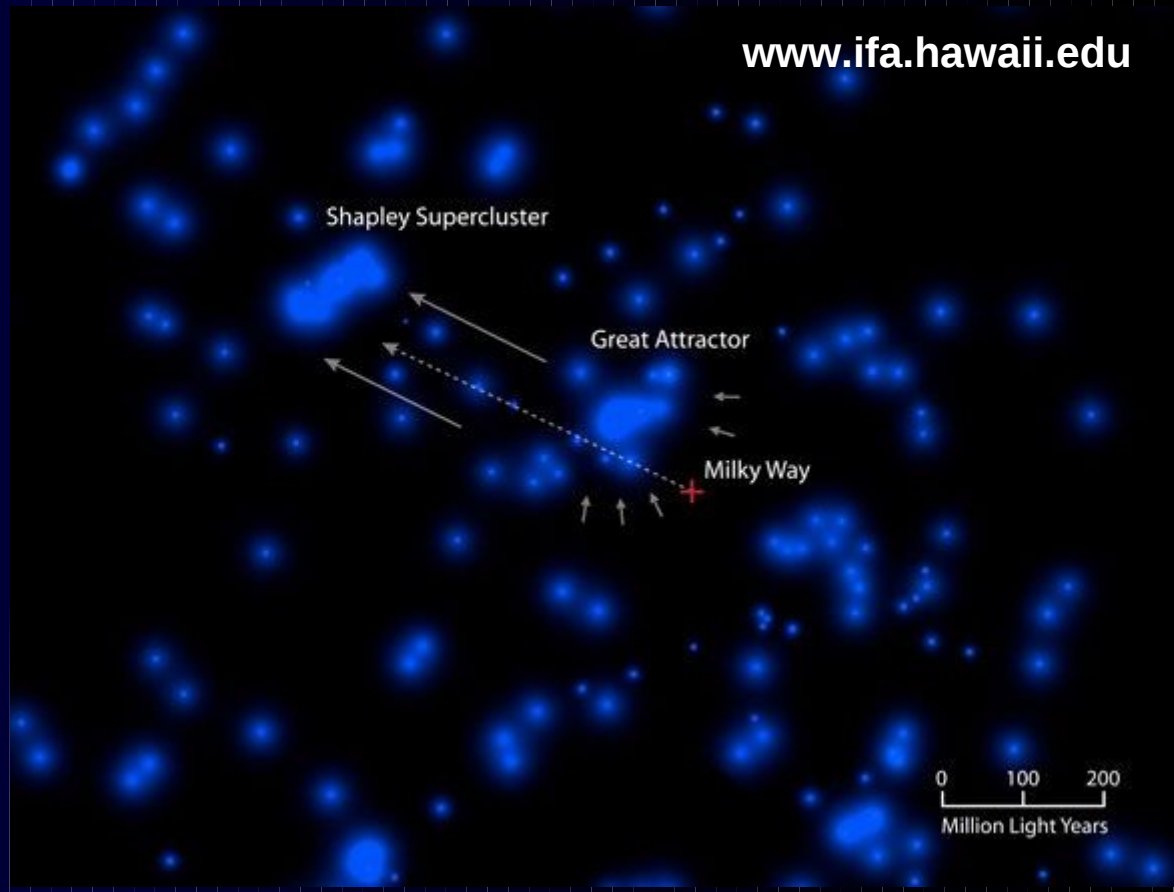
- Overdensities cause gravitational attraction and lead to bulk flows and peculiar velocities



2MASS (T. Jarrett et al.)

SN Ia as peculiar velocity tracers

- Inhomogeneities/anisotropies since ~50 years
- large scale structures, deviations in Hubble flow
- SN Ia tracing local flows (e.g. Riess et al. 1995)
- Bulk flow in the nearby universe towards GA/SSC/CMB dipole
- Colin et al. (2011): SSC imprinted in Union2 dataset
- We studied the nearby universe (z<0.1) using 117 SN Ia 0.014<z<0.12 from the Nearby Supernova Factory



Smoothing residuals Method

(Colin et al. 2011 MNRAS 2011)

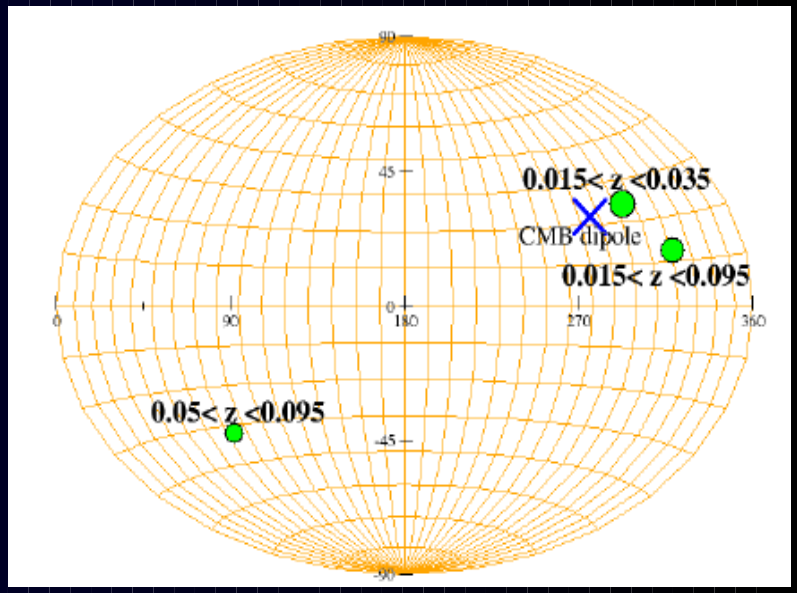
- Smoothing of Hubble residual with Gaussian weights depending on SN distance

$$Q(\theta,\phi) = \sum_{i=1}^{N} q_i(z_i,\theta_i,\phi_i) W(\theta,\phi,\theta_i,\phi_i)$$

$$W(\theta,\phi,\theta_i,\phi_i) = \frac{1}{\sqrt{2\pi}\delta} \exp\left[-\frac{L(\theta,\phi,\theta_i,\phi_i)^2}{2\delta^2}\right]$$

$$\Delta Q_{\mathrm{data}} = Q(\theta_{\max},\phi_{\max}) - Q(\theta_{\min},\phi_{\min})$$

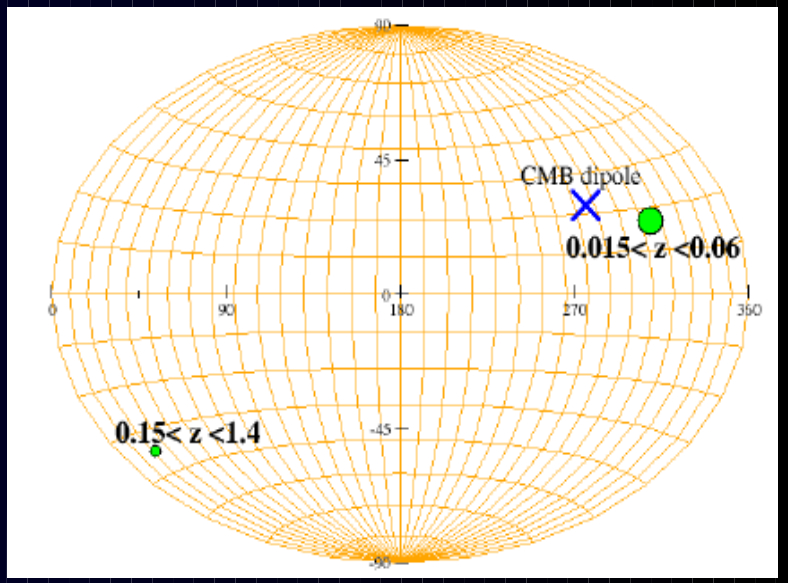
q... residuals, *W*... weights, *L*... SN pair distance on unit sphere



Shapley Infall

- Analysis of different redshift bins in Union2
- Find anisotropy pattern at 2-3 sigma level consistent with direction of the Shapley Superluster (SSC) (z~0.035-0.055):

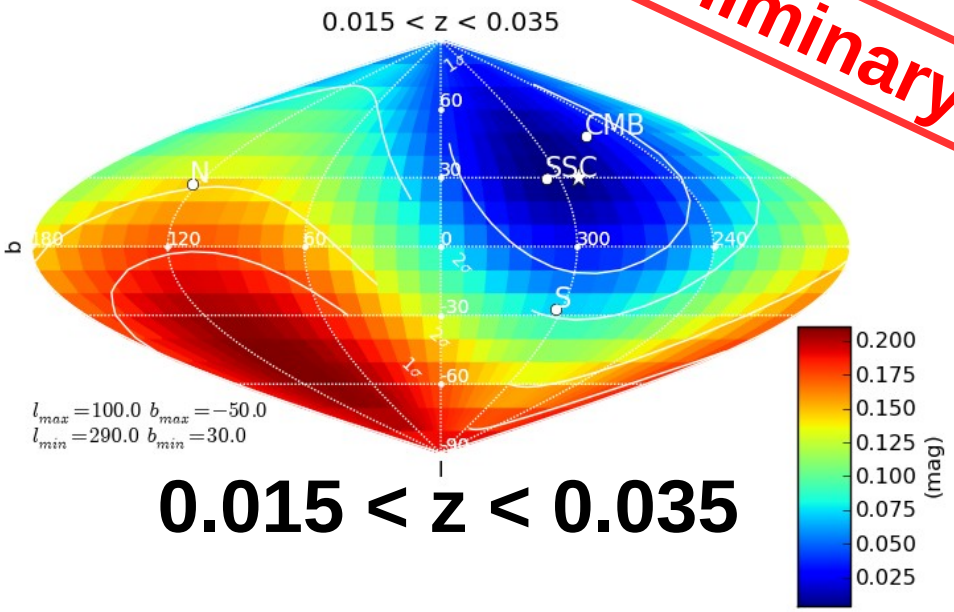
"We show that the Union 2 data provide the first evidence of the infall on to Shapley; SNe Ia which are falling away from us and towards Shapley are statistically dimmer than those which lie beyond this supercluster and are falling towards us."



At small redshifts z<0.06 isotropic universe lies 2-3σ away from data

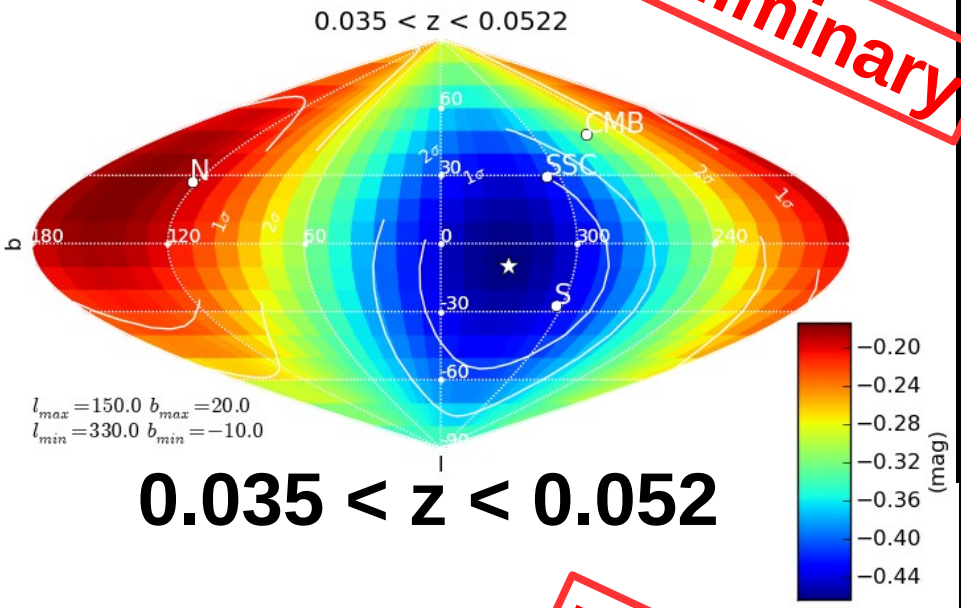
Union2 re-investigated

2.8 σ Preliminary



0.015 < z < 0.035

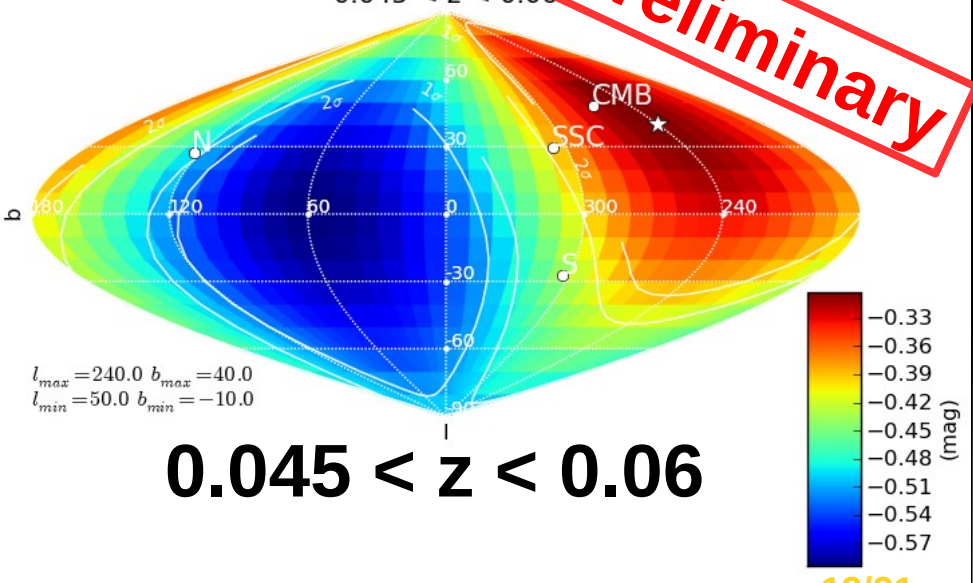
3.3 σ Preliminary



0.035 < z < 0.052

- **SSC: <z> 0.046, 0.035<z<0.055, (l,b)=(306.44,29.71)**
- **YES in Union2 there seems to be an (insignificant) "turnaround" of the dipole around the SSC**

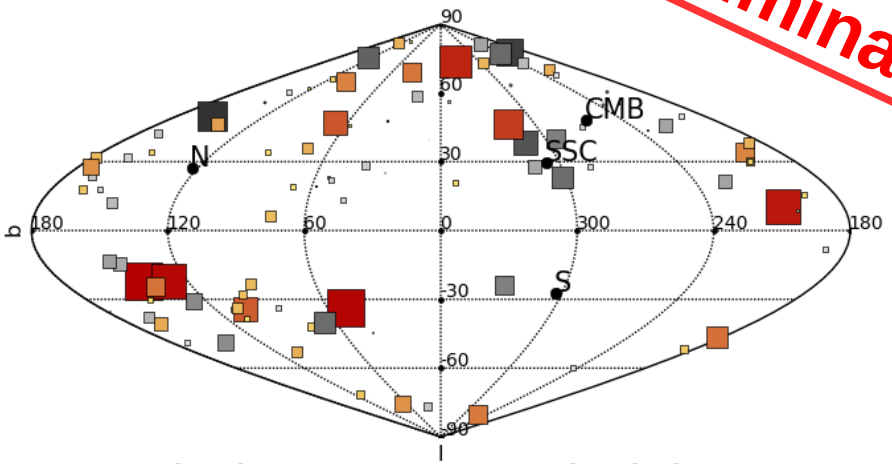
1.9 σ Preliminary



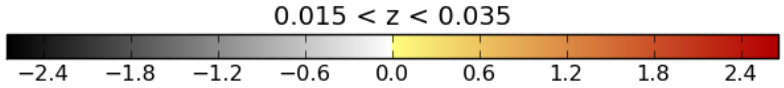
0.045 < z < 0.06

Union2 re-investigated

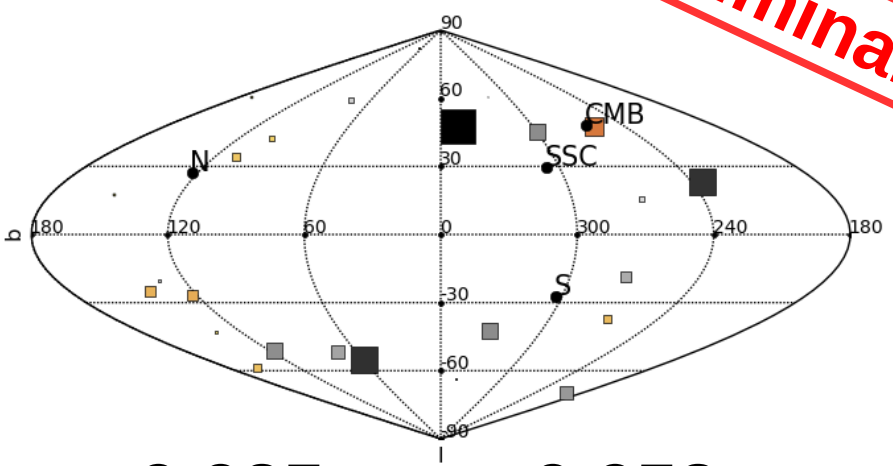
2.8 σ Preliminary



0.015 < z < 0.035

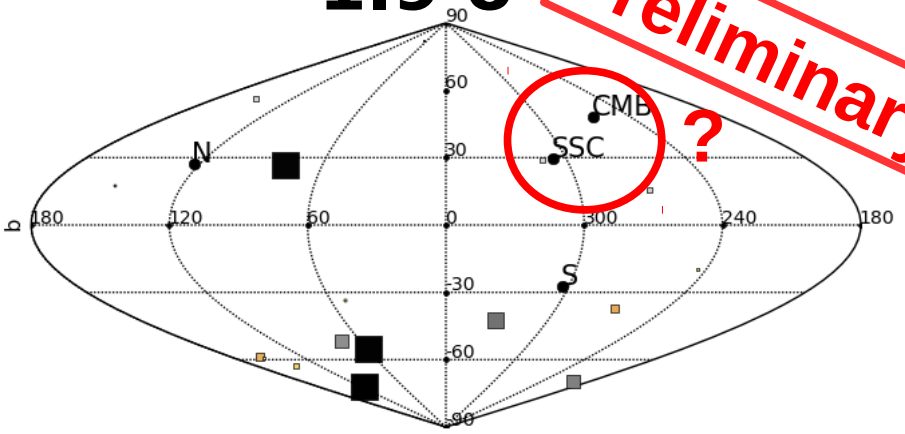


3.3 σ Preliminary

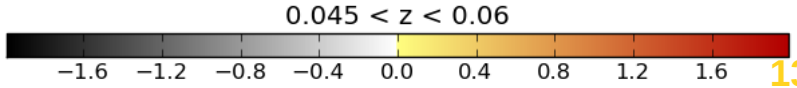


0.035 < z < 0.052

1.9 σ Preliminary ?



0.045 < z < 0.06

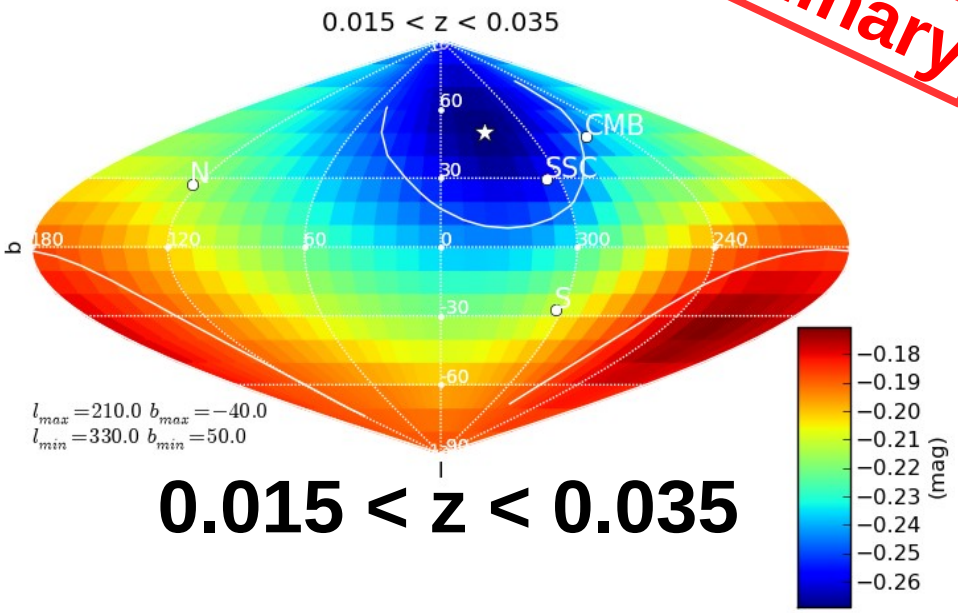


- **SSC: <z> 0.046, 0.035<z<0.055, (l,b)=(306.44,29.71)**
- **NO it does not seem to be SNe falling towards Shapley since the data coverage in Union2 is too sparse in the corresponding bin!!**

Nearby Supernova Factory Data

0.6 σ

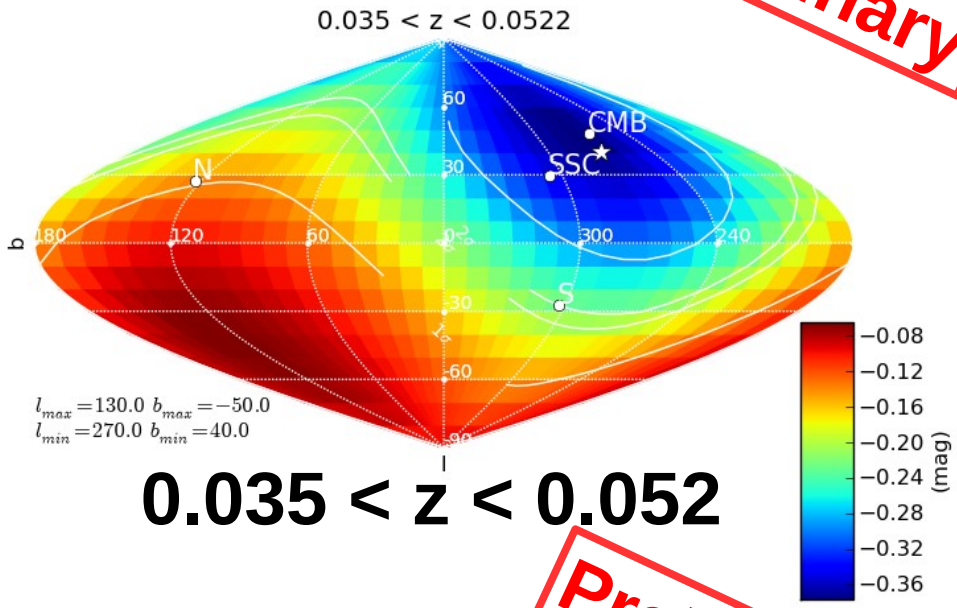
Preliminary



0.015 < z < 0.035

1.6 σ

Preliminary



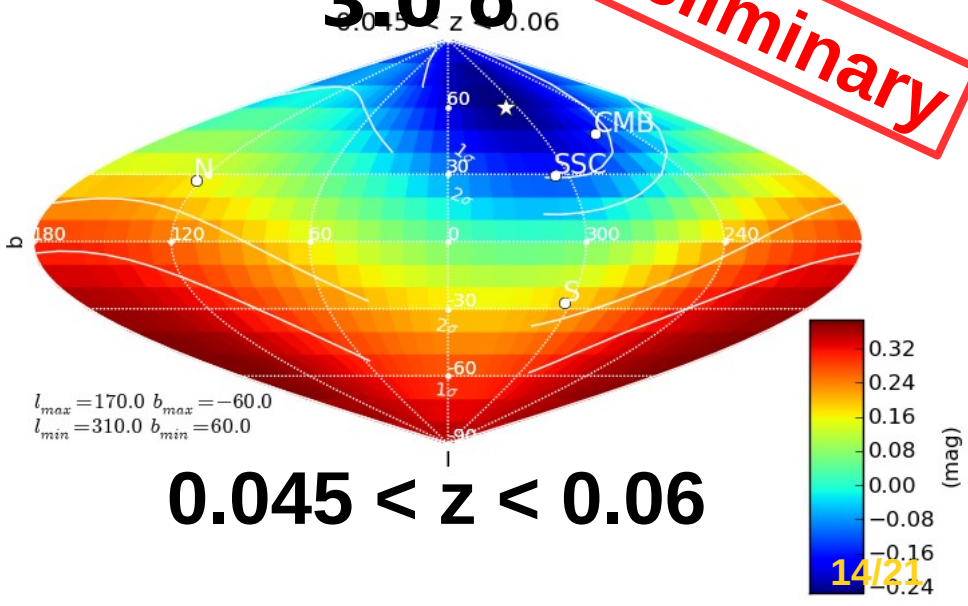
0.035 < z < 0.052

- **No turnover in SNF data.**

Flow stays in the same direction at the 3σ level!

3.0 σ

Preliminary

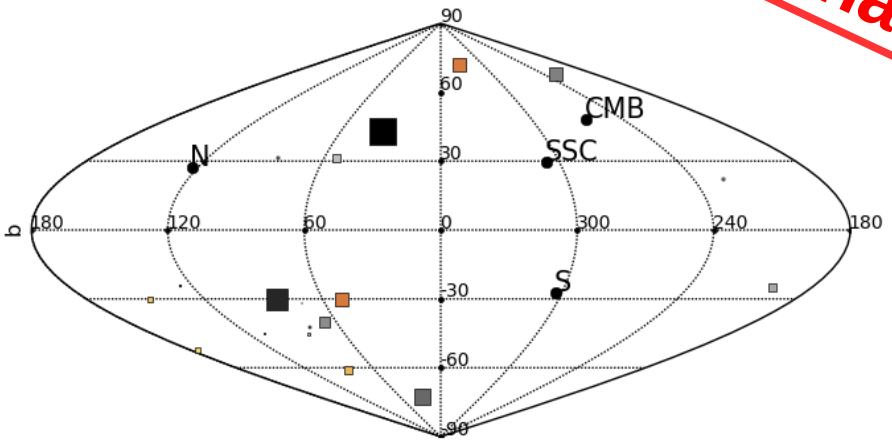


0.045 < z < 0.06

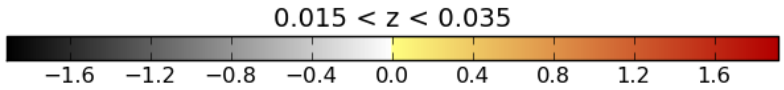
Nearby Supernova Factory Data

0.6 σ

Preliminary

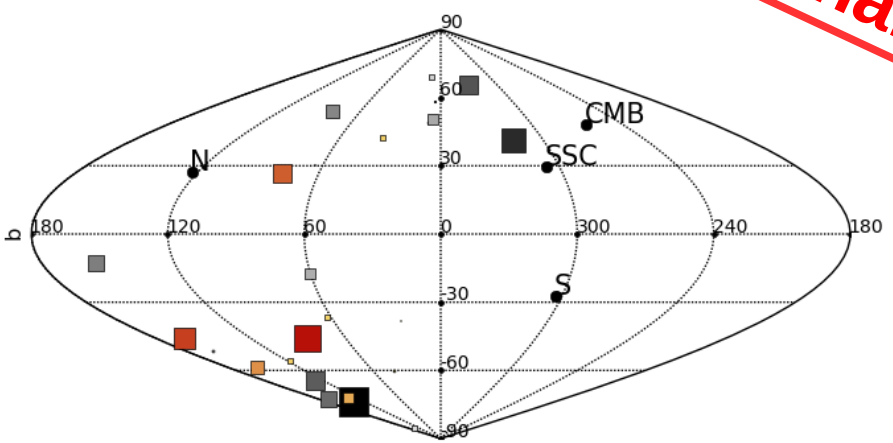


0.015 < z < 0.035

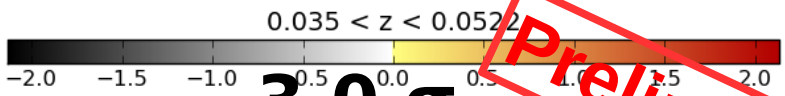


1.6 σ

Preliminary

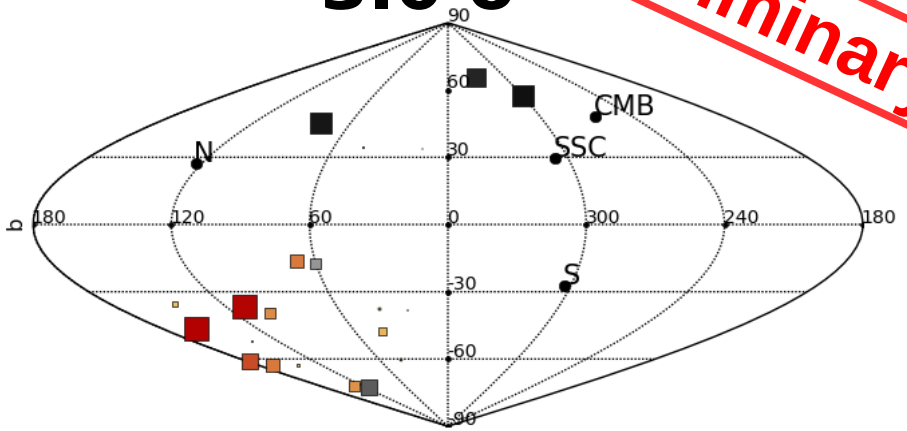


0.035 < z < 0.052

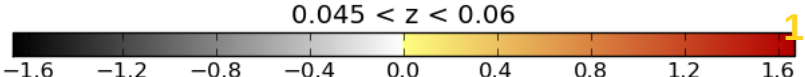


3.0 σ

Preliminary



0.045 < z < 0.06



- **No turnover in SNF data.**

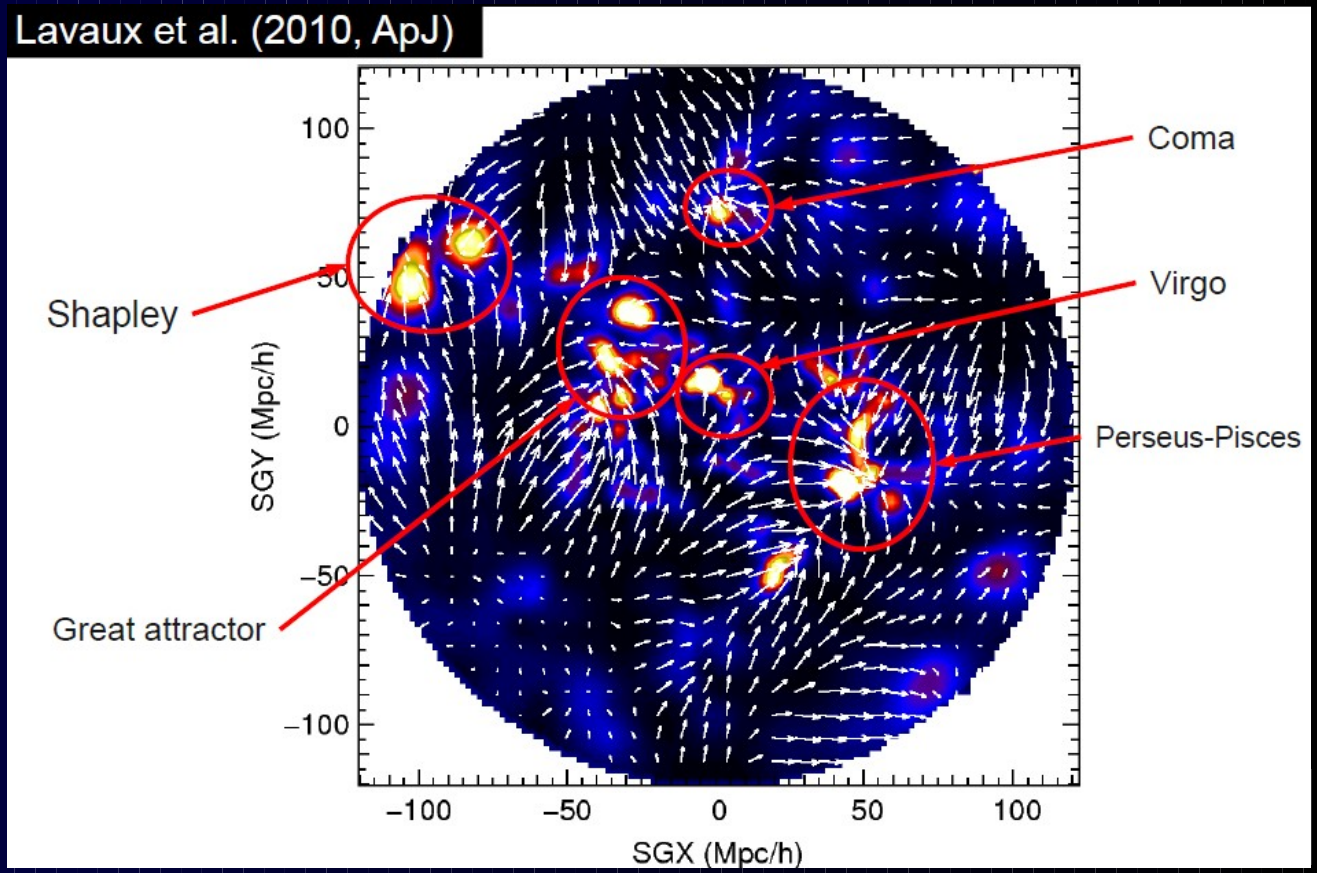
Flow stays in the same direction at the 3σ level!

Gravitational Attractor Picture

Following Peebles (1993), Munoz et al (2008)

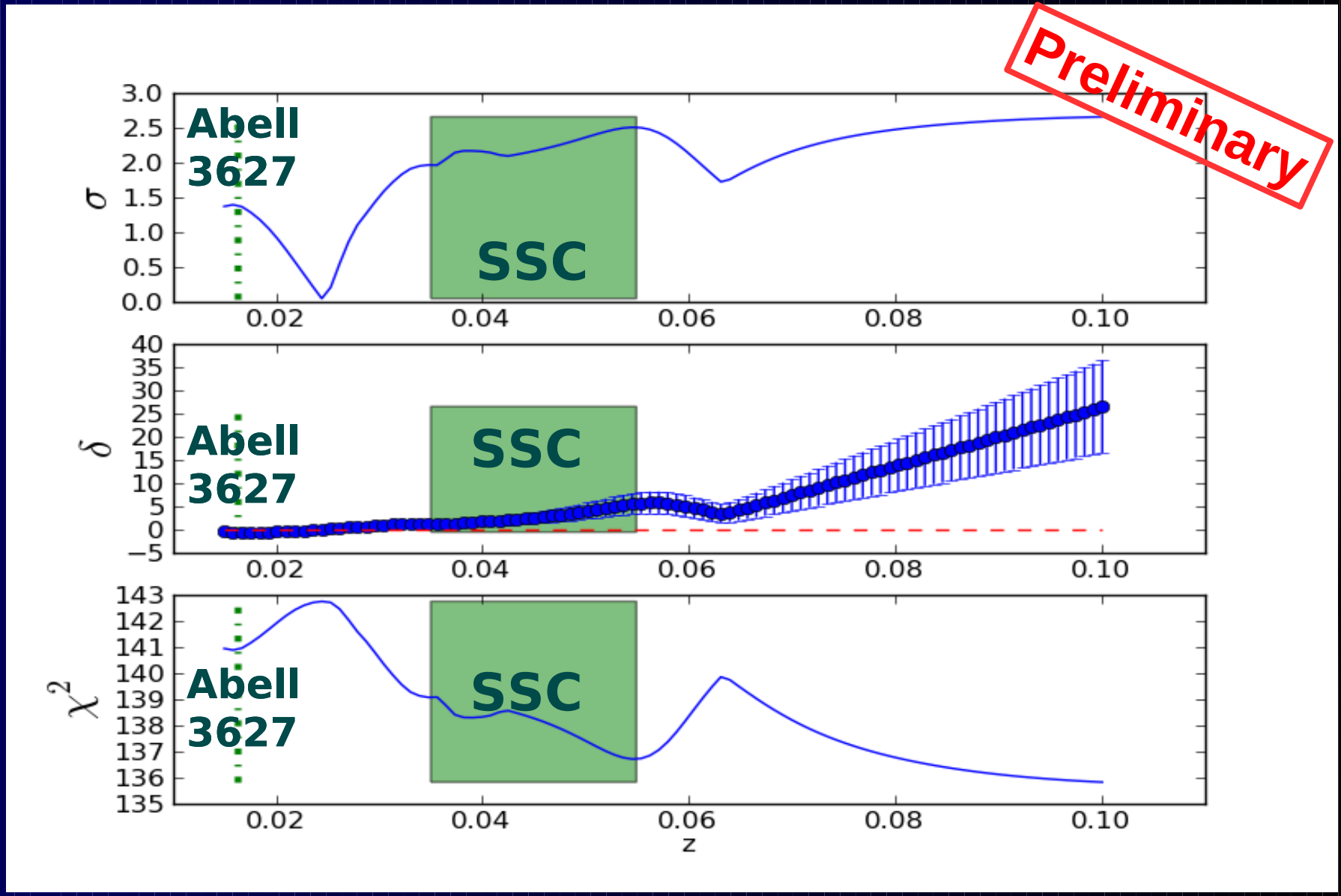
$$M_{tot}(< R_E) = (4/3)\,\pi\, R_L^3\, \Omega_{M,0}\, \rho_{crit,0}\, (1+\delta_i)$$

$$v_p = \frac{a\, f\, H}{4\,\pi} \int \frac{\vec{y}-\vec{x}}{|\vec{y}-\vec{x}|^3}\, \delta(\vec{y})\, d^3\vec{y}$$



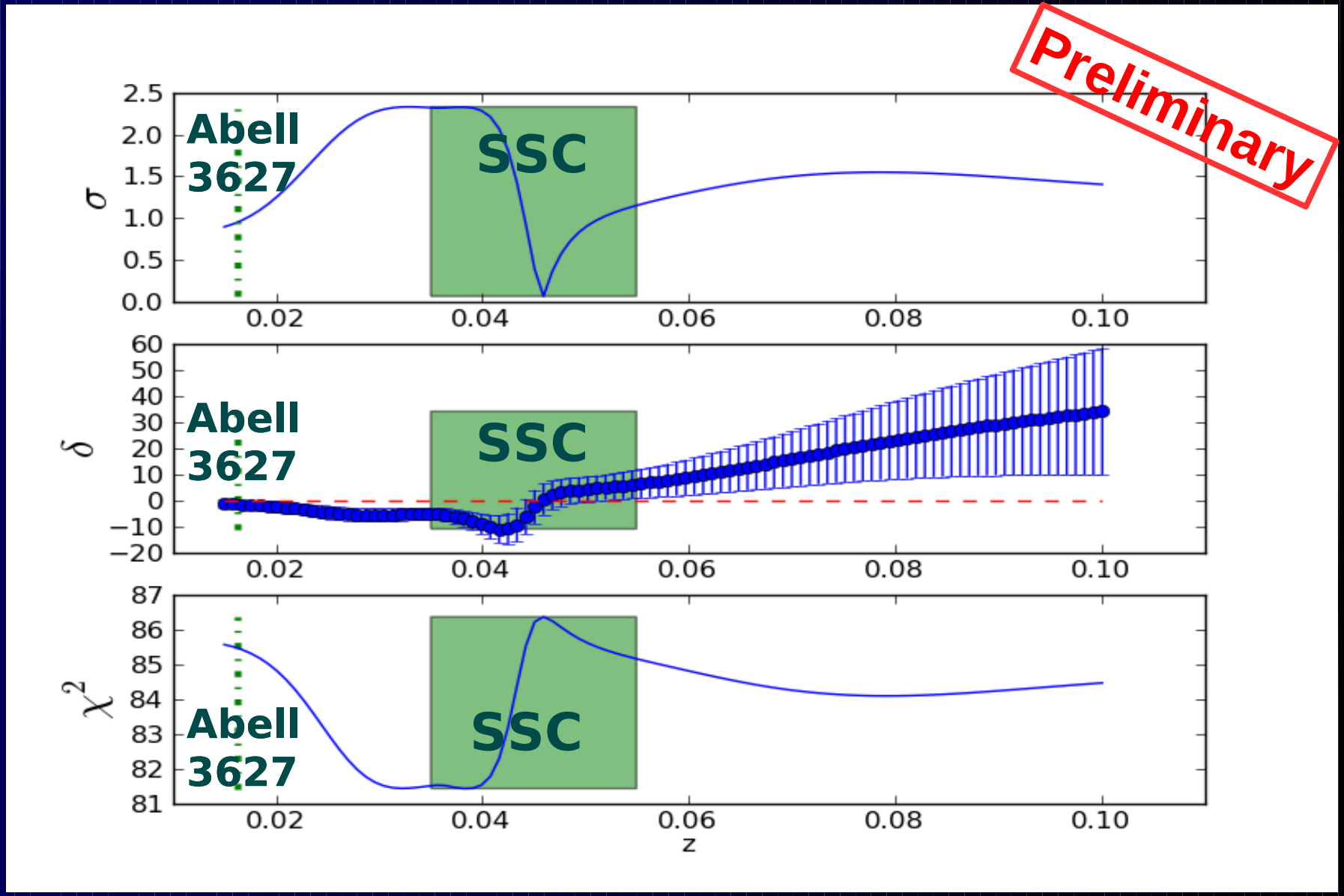
Compute velocity field from SN data and infer attractor mass (overdensity δ) at different z positions along the LOS towards SSC

Union2



Union2 in principle consistent with an (increasingly unrealistic) overdensity at SSC location. BUT: no blue shifted SNe in the outer rims of the cluster in the union2 data!!

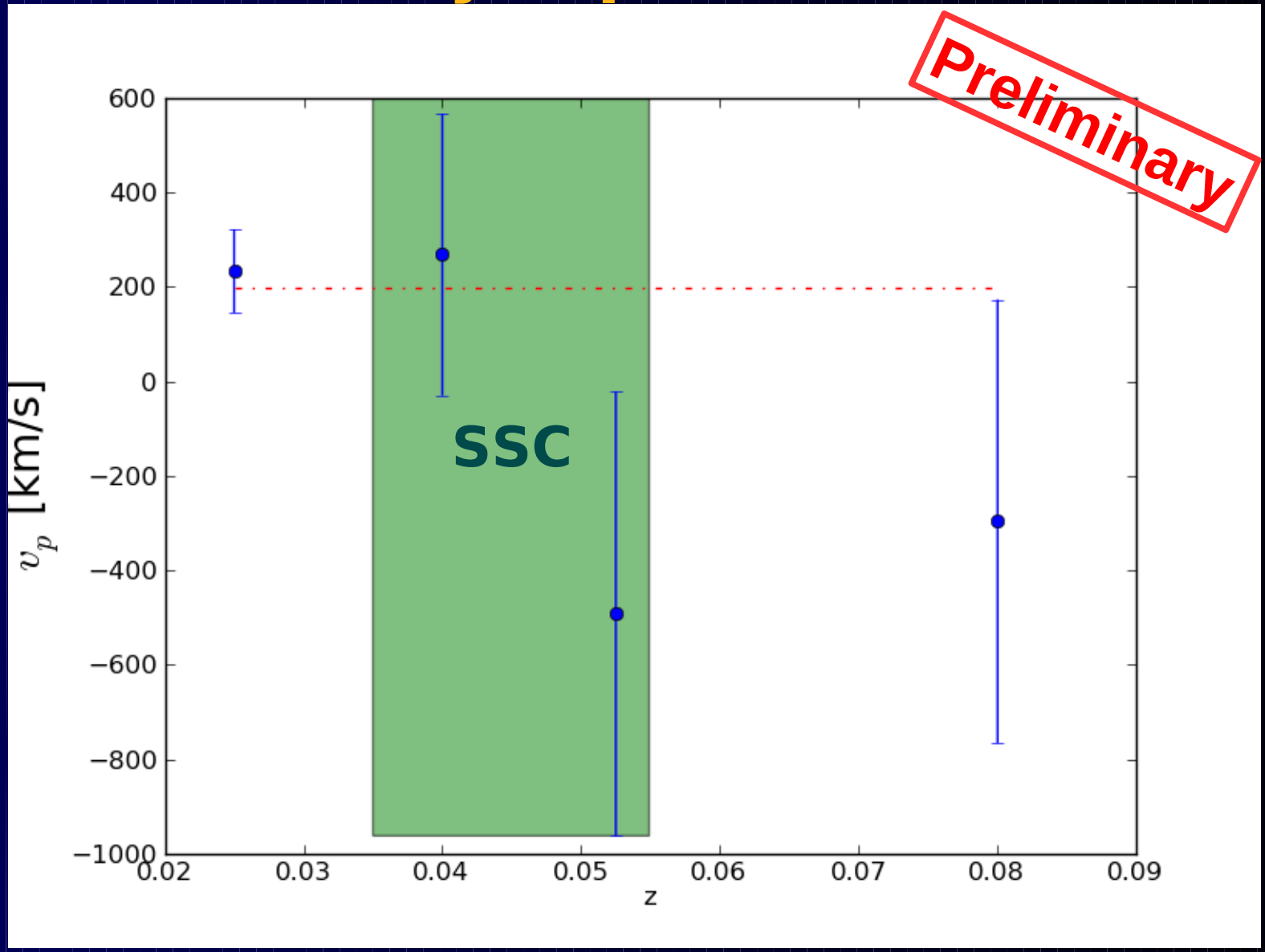
SNF ACEv3



SNF data is incompatible with the SSC (attractor) scenario at the 2.3 σ level!

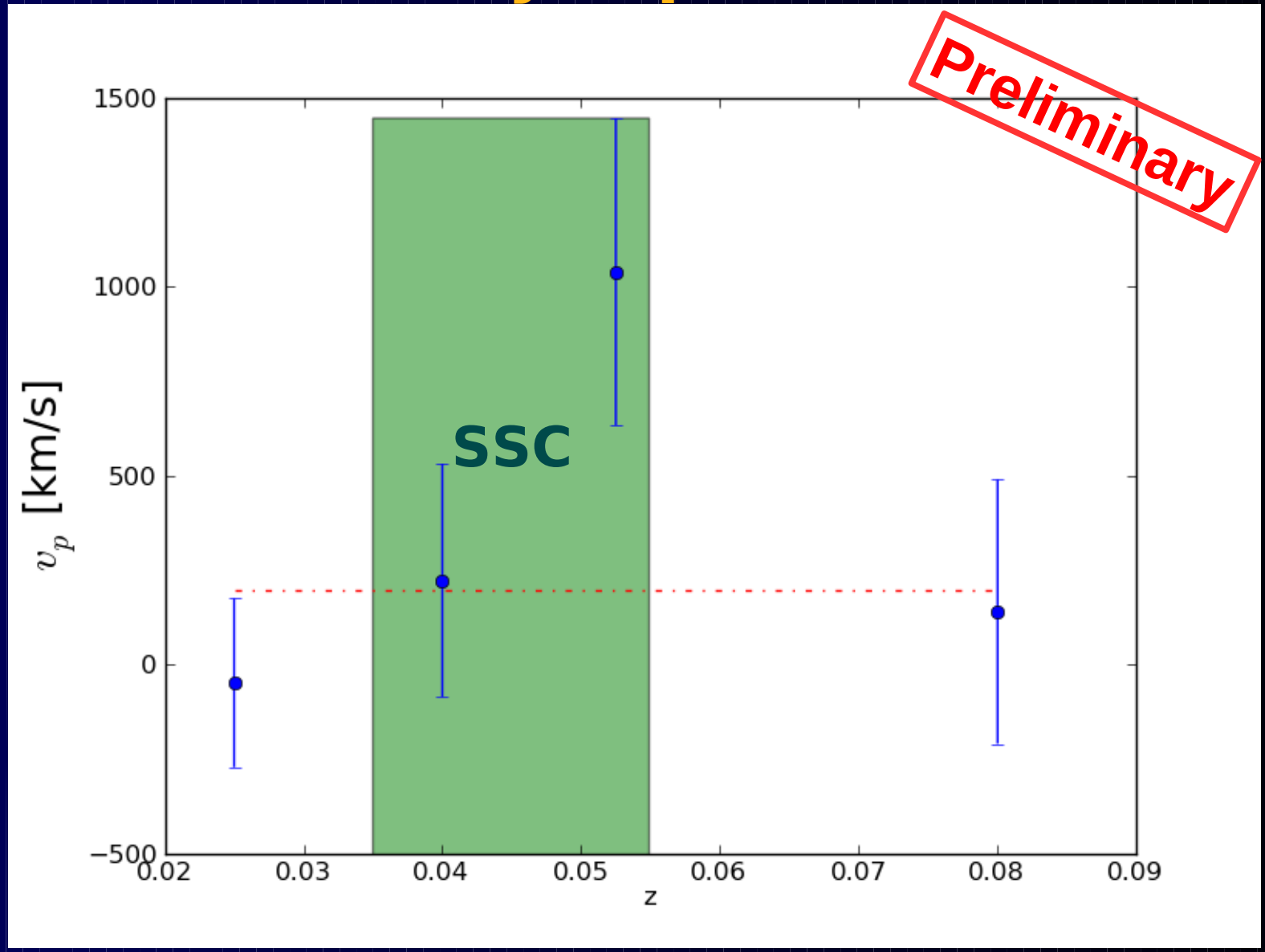
Remember: SNF has red shifted SNe in the outer SSC region!

Velocity Dipole Union2



- Overall dipole amplitude of ~200 km/s towards SSC
- Signal comes mainly from bin 0.015<z<0.035
- Inconclusive w.r.t. bulk flow beyond SSC

Velocity Dipole SNF



- Overall dipole amplitude of ~200 km/s towards SSC
- Signal comes mainly from bin 0.045<z<0.06
- Hints for bulk flow extension beyond SSC but not further

Conclusions

- We know of a 2-3 σ dipole flow in direction of Shapley/CMB from galaxy and SN data.
- Union2 cannot prove that SSC is solely responsible for the detected bulk flow
- The signature in the SNF data also does not support such a scenario.
- The bulk flow motion seems to extend slightly beyond Shapley.