# Investigating anisotropies in the local universe with the Nearby Supernova Factory

TR33 - Summer Institute:
Particles and the Universe

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**For the Nearby Supernova Factory**

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# The Nearby SNfactory

**The Nearby Supernova Factory (Aldering et al. 2002) aims to improve supernova cosmology by:**

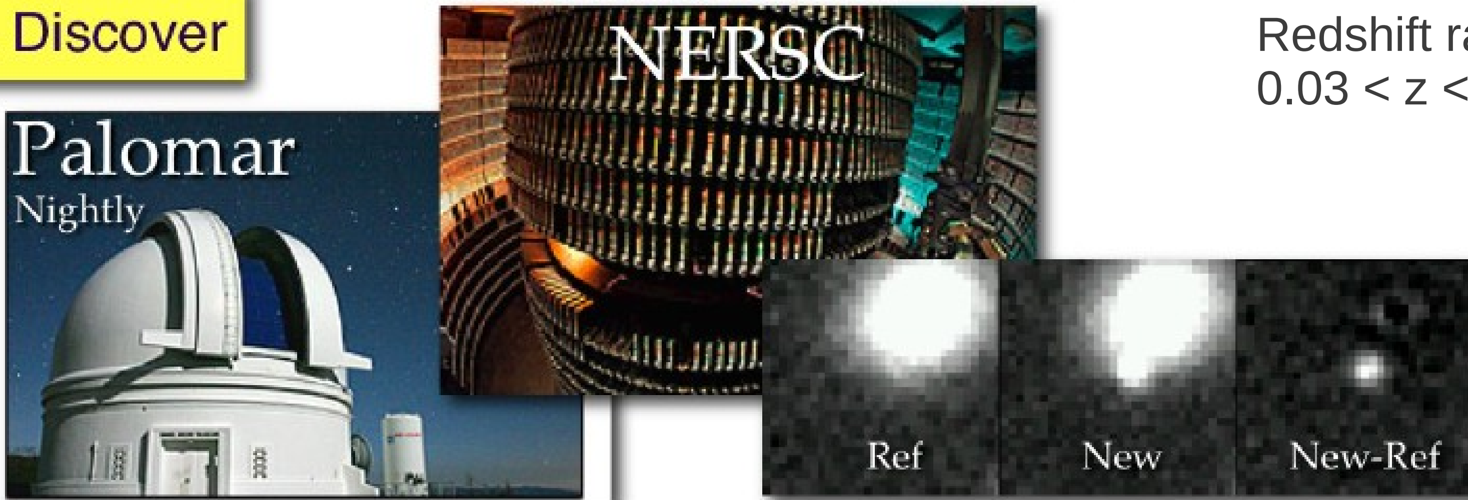
- **obtaining time series of flux-calibrated spectra of type Ia supernovae (SNe Ia) at $0.03 < z < 0.08$**
- **better understanding the phsyics associated with SN Ia explosions**
- **improving the standardization of SNe Ia and the measurement of their absolute magnitude**

**Collaborating labs:**

**LBNL (Berkeley), Yale, LPNHE (Paris), IPNL&CRAL (Lyon), CPPM (Marseille), MPA (Garching), Bonn U., Tsinghua U. (Beijing)**

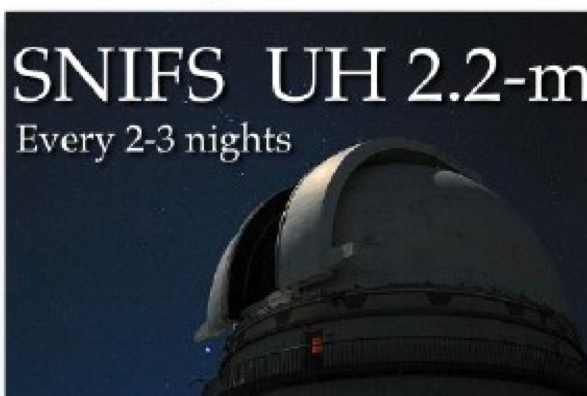
# The Nearby SNfactory

1. Discover



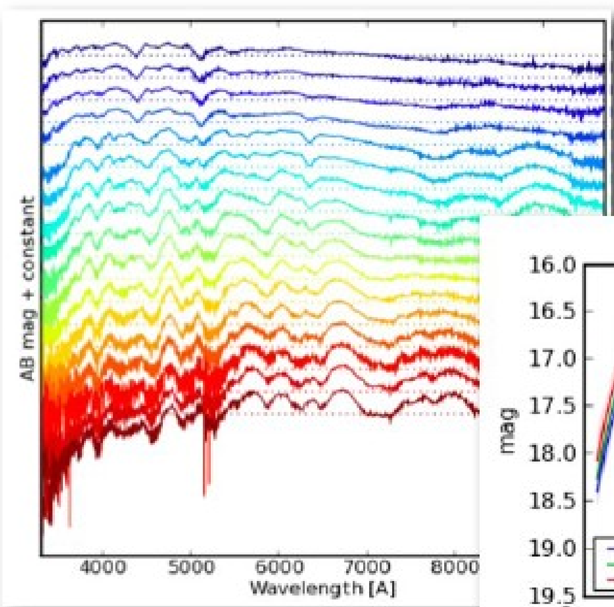

Redshift range:
0.03 < z < 0.08

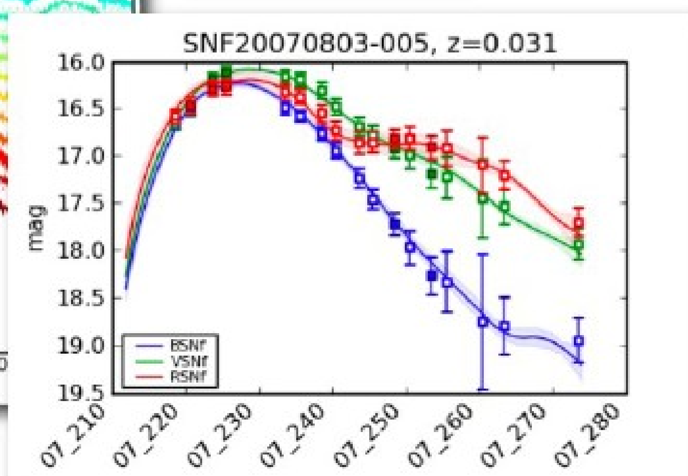
2. Observe




Custom, unique spectrometer
designed for nearby SN obs

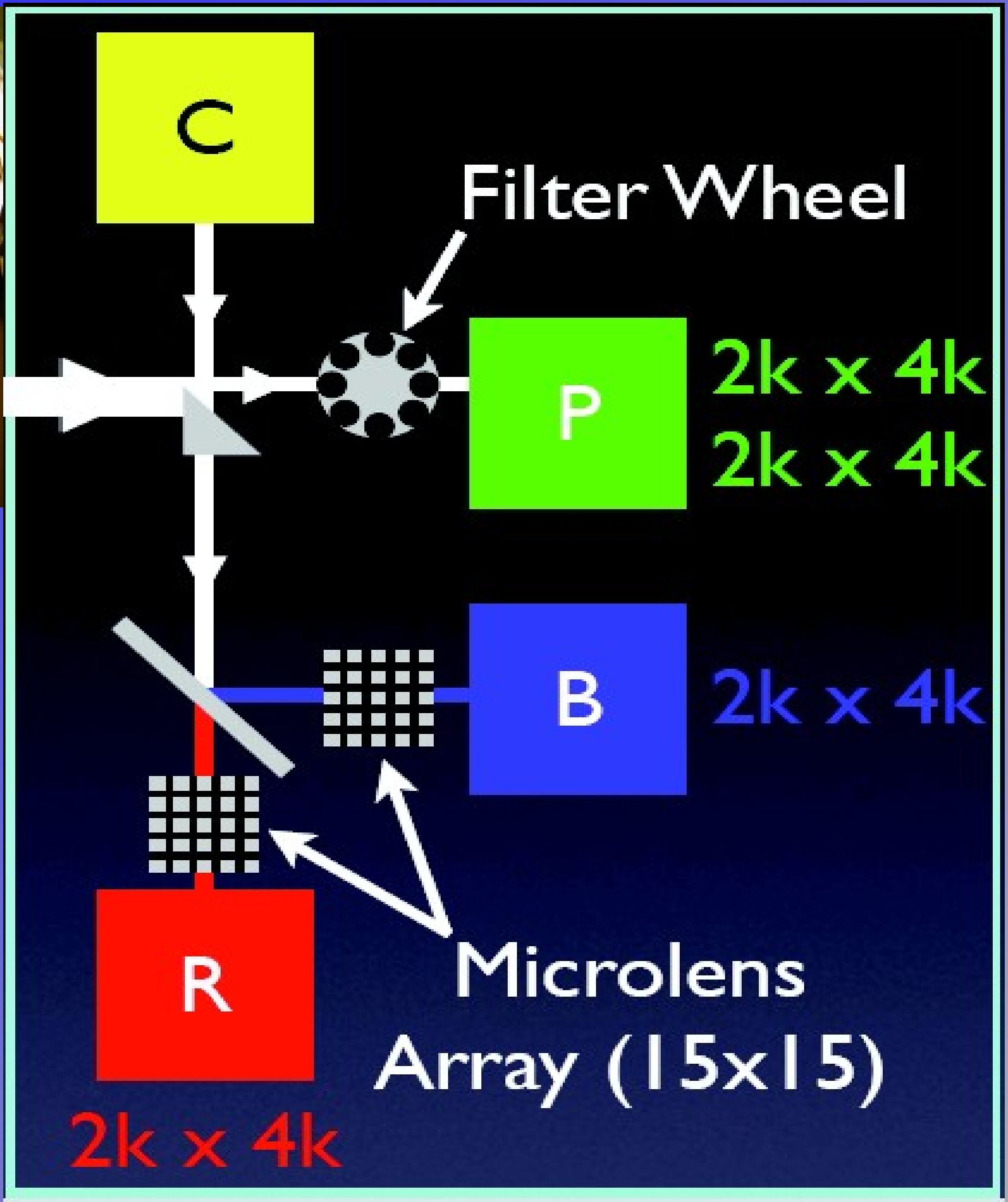
3. Analyze

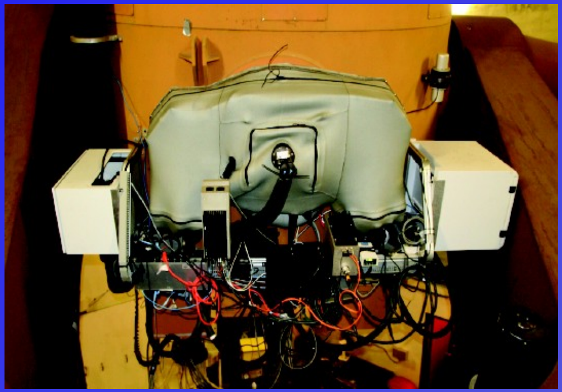


# Supernova Integral Field Spectrograph (SNIFS)

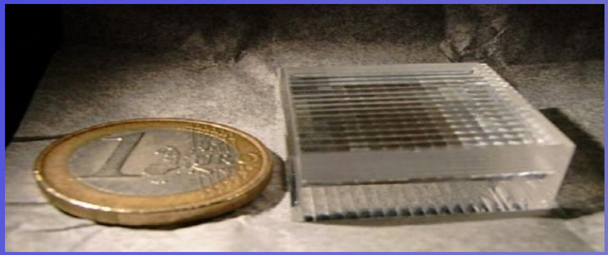
UH 2.2m

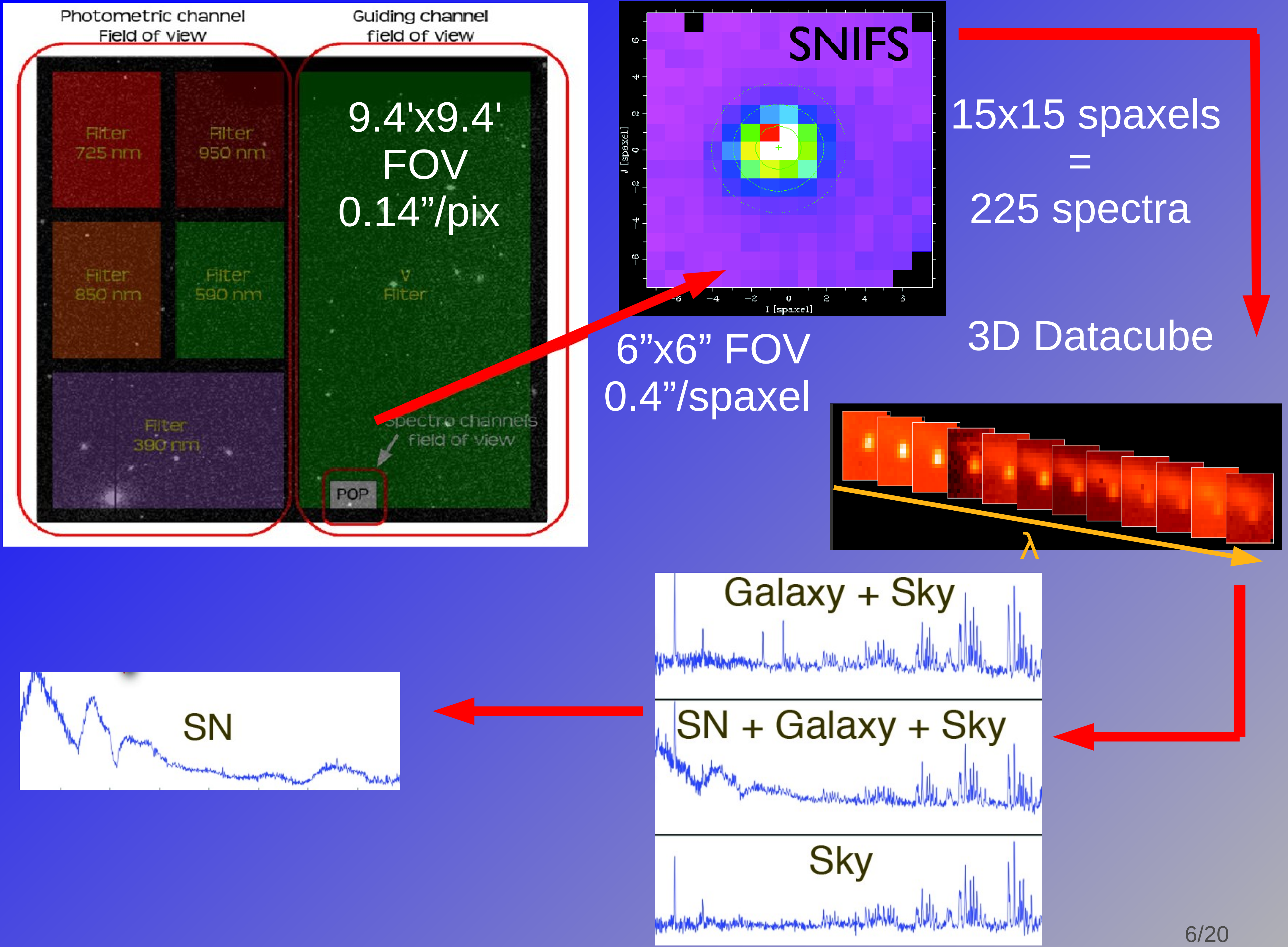


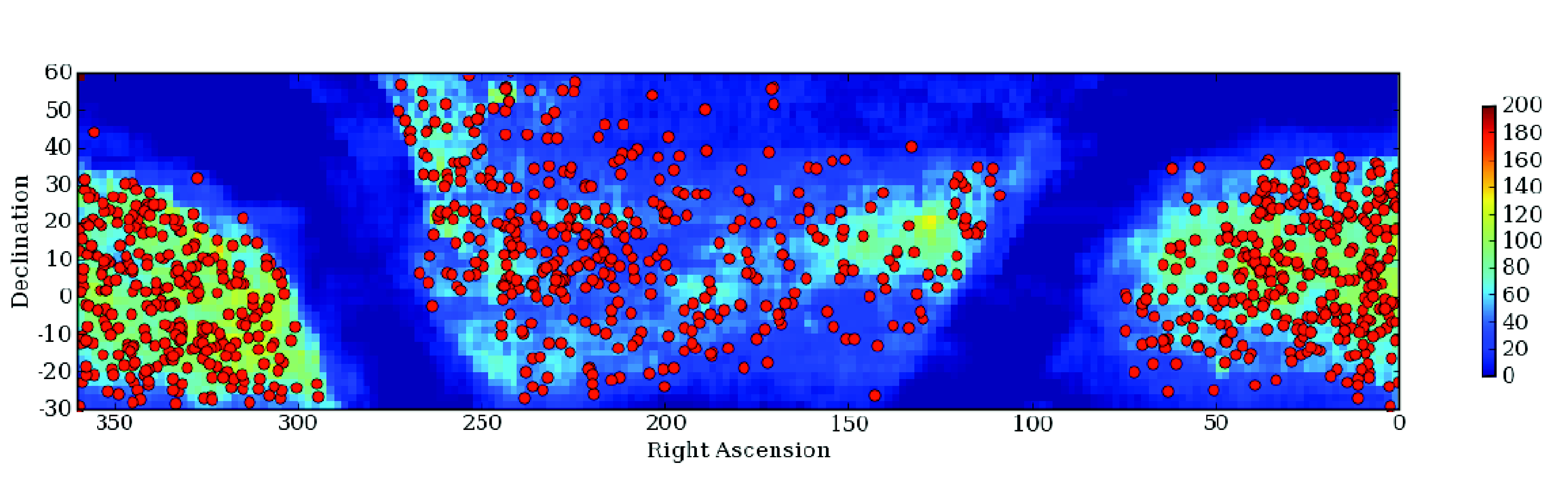
SNIFS

Microlens Array

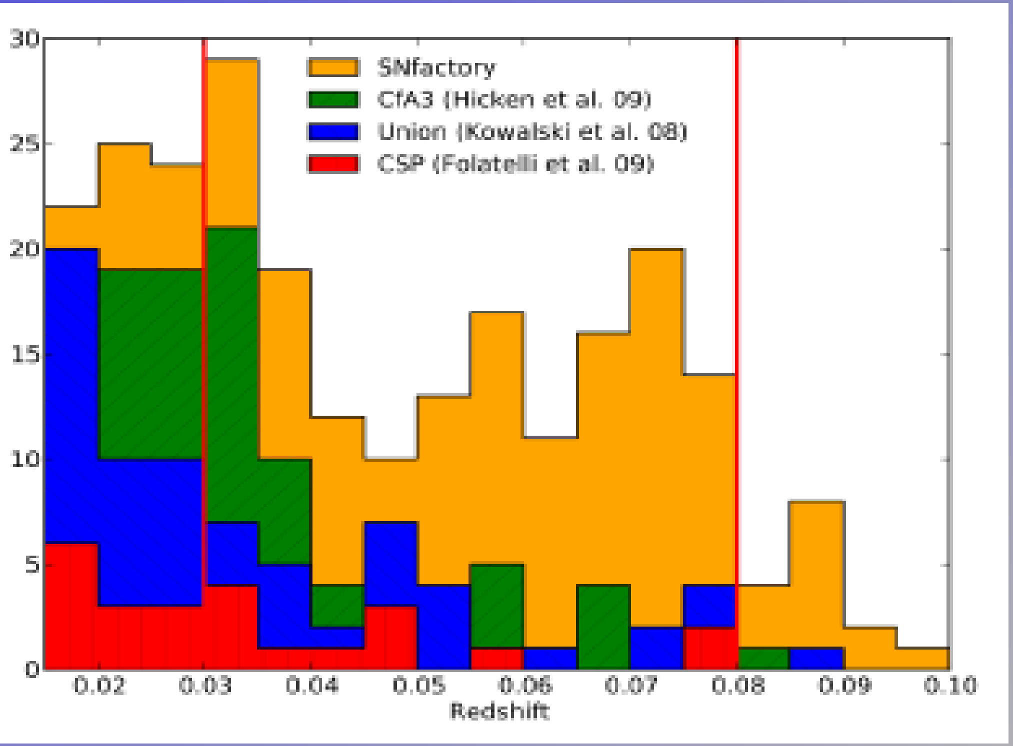



Photometric channel
Field of view
Guiding channel
field of view
Filter 725 nm
Filter 950 nm
Filter 850 nm
Filter 590 nm
Filter 390 nm
9.4'x9.4'
FOV
0.14"/pix
V Filter
Spectro channels
field of view
POP
SNIFS
15x15 spaxels
=
225 spectra
6"x6" FOV
0.4"/spaxel
3D Datacube
λ
Galaxy + Sky
SN + Galaxy + Sky
Sky
SN

# The SNF Dataset

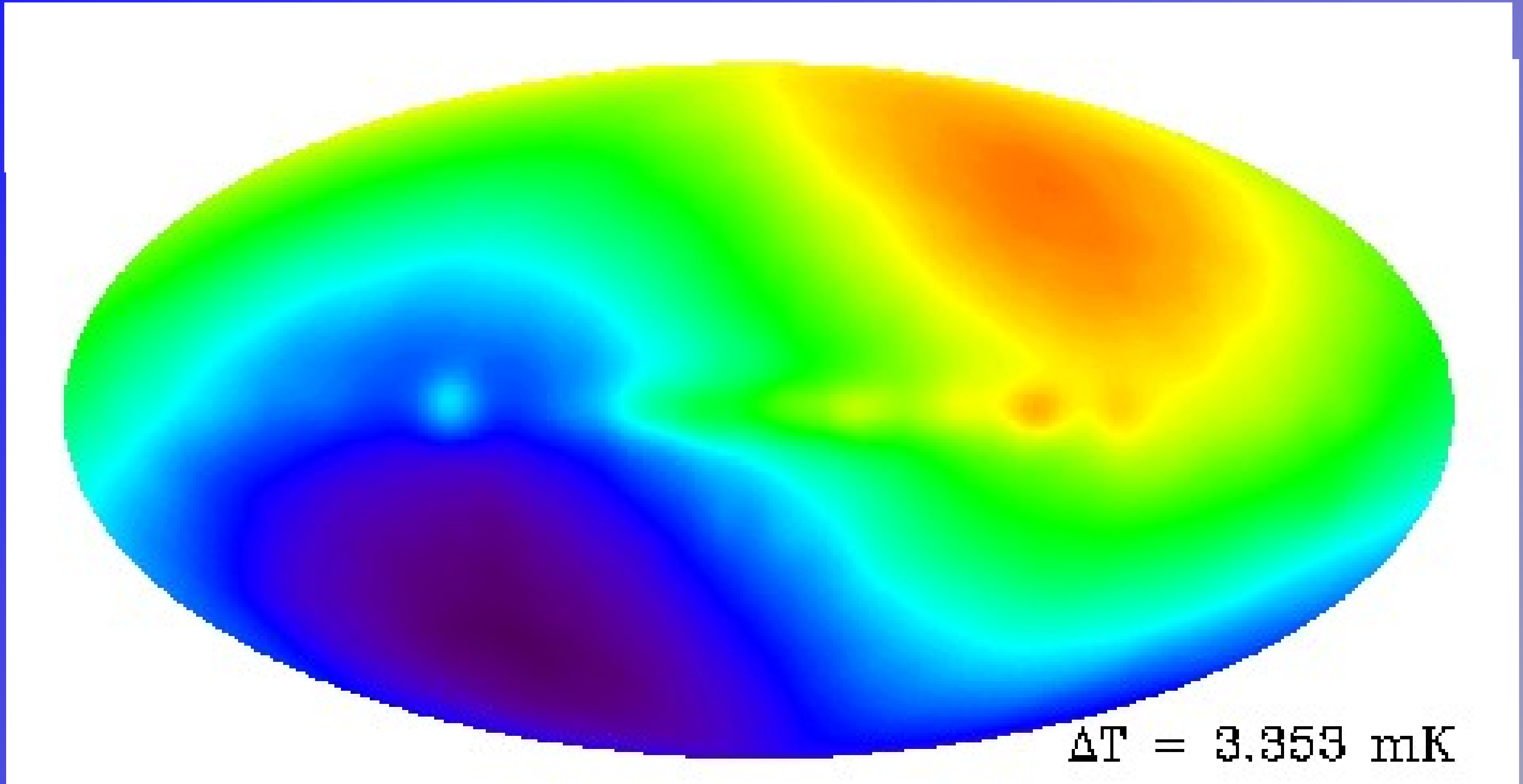



| | SNfactory | Others | Total |
|---|---|---|---|
| SN | ~620 | ~70 | ~690 |
| SN Ia | ~400 | ~50 | ~450 |
| Follow-up | ~150 | ~40 | ~190 |



# Bulk Flow in the Local Universe

**CMB dipole arises from peculiar motion of the Local Group at 627±22 km/s (Kogut et al. 1993)**




COBE 4yr data (Bennet et al. 1996)

# Reason for Bulk Flow?

**CMB dipole arises from peculiar motion of the Local Group at 627±22 km/s (Kogut et al. 1993)**

**What causes the bulk flow?**

- **Local overdensity (e.g. Shapley Supercluster)?**
- **Structures at larger distances?**
- **"Dark Flow" (Kashlinsky et al. 2012)?**

**What is its redshift behavior?**

# SNe Ia as peculiar velocity tracers

**Galaxies have been used to trace peculiar motion for more than 30 years**

- Luminosity distance precision: ~ 15 – 25%
- Methods practical only up to ~ 100 – 200 Mpc (z ~ 0.025 - 0.05)

**Recently kinetic Sunyaev-Zeldovic (kSZ) effect of clusters (or the galaxies themselves) has been used**

- Large systematic uncertainties in the models
- Few clusters at $z < 0.1$

**Type Ia Supernovae**

- Luminosity distance precision: typically ~ 8 %
- Observable up to very high redshift
- Data in relevant redshift range ($0.05 < z < 0.1$) still sparse but large increase in statistics expected.

# Anisotropy Analysis

## (with M. Kehrschhaggl)

- **Bulk flow corresponds to a dipole term in the luminosity distance:**

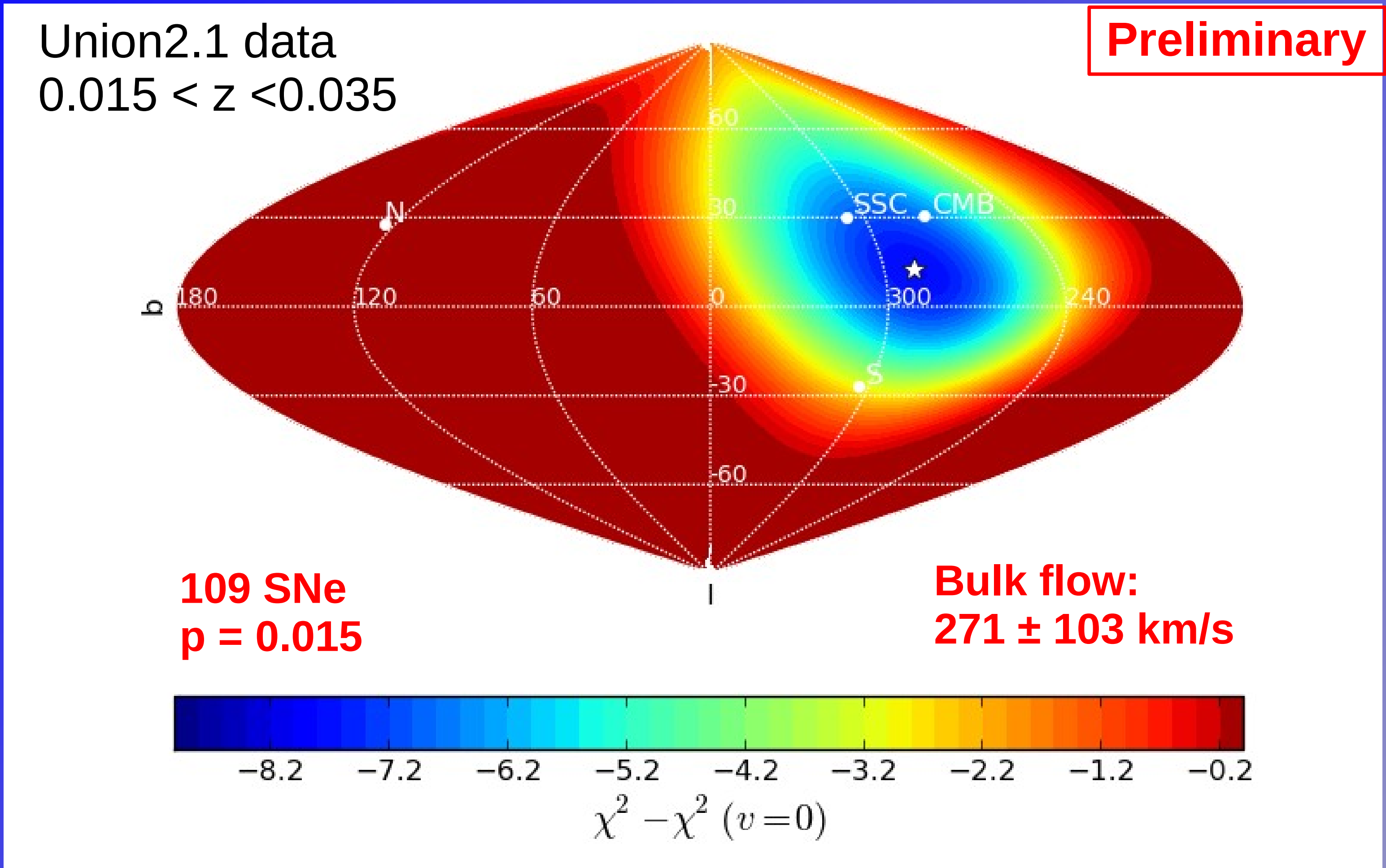
$$d_L(z, v_p, \theta) = d_L^{(0)}(z) + d_L^{(1)}(z, v_p) \cdot \cos(\theta)$$

$$d_L^{(1)}(z, v_p) = \frac{v_p(1+z)^2}{H(z)}$$

(Bonvin et al. 2006)

- **Used the Union 2.1 compilation (Suzuki et al. 2011) and the SNfactory data set**
- **Fit dipole to determine bulk flow in redshift shells**
- **Concentrated on shells around the Shapley Supercluster, the largest mass concentration in the nearby universe, at 0.035 < z < 0.055**

# Dipole Fit




- $\chi^2$ of dipole fits depending on the dipole direction and $v > 0$ compared to Hubble fit without bulk flow
- p-value determined from 5000 random resamplings

# Smoothing residuals Method

- **Implemented the test statistics used by Colin et al. 2011**
- **Smoothing of Hubble residuals with Gaussian weights depending on angular distance on unit sphere**

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

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

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

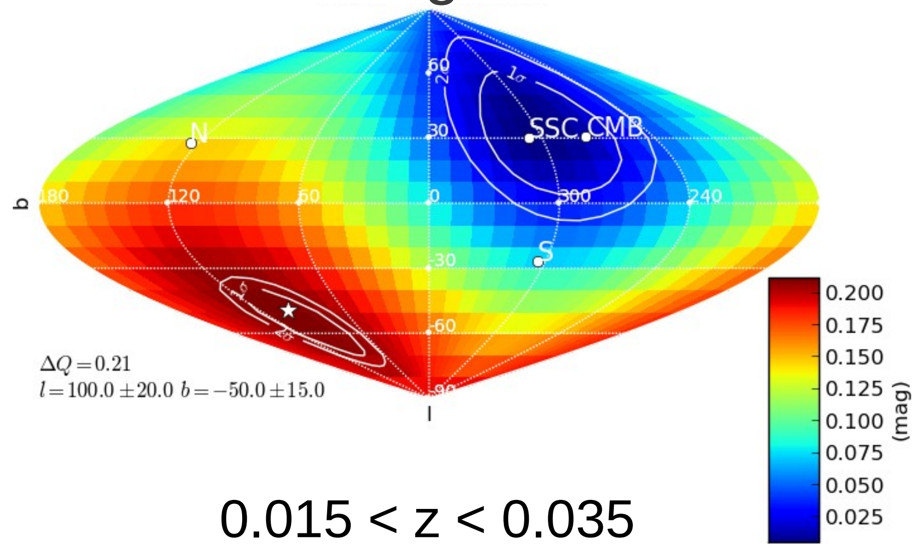
*q*... residuals, *W*... weights, *L*... SN pair distance on unit sphere

- **Results are consistent with the dipole fits**

Union2.1 data

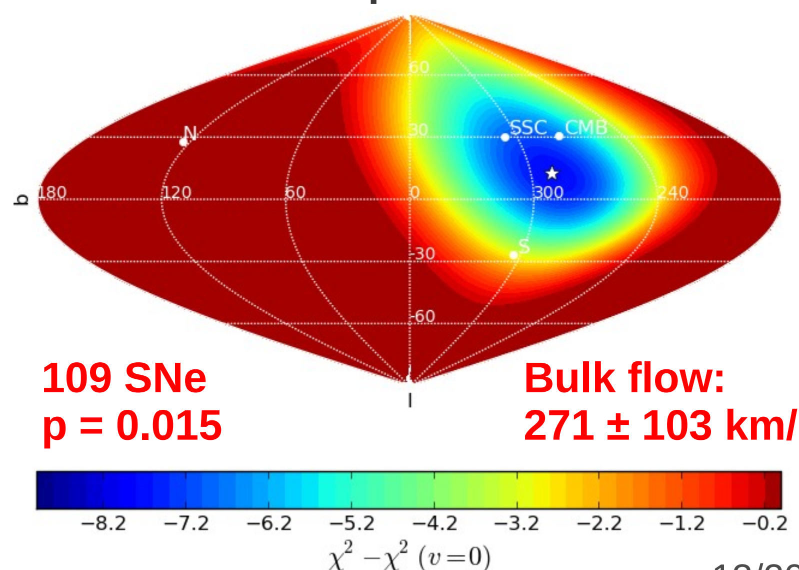
**Preliminary**

Smoothing residuals




0.015 < z < 0.035

Dipole fit



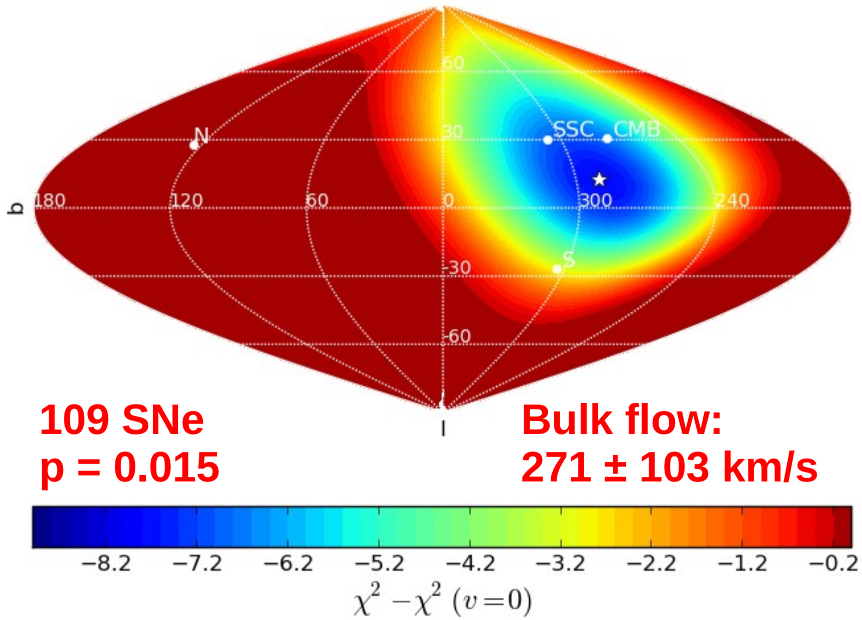

**109 SNe**
**p = 0.015**

**Bulk flow:**
**271 ± 103 km/s**

# Union2.1

Preliminary

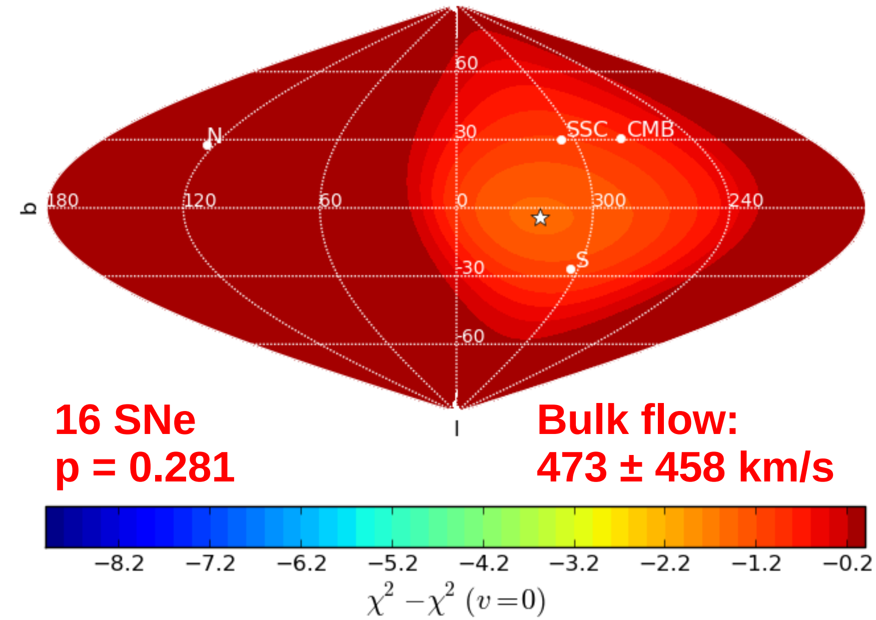
0.015 < z < 0.035




**109 SNe**
**p = 0.015**

**Bulk flow:**
**271 ± 103 km/s**

0.035 < z < 0.045

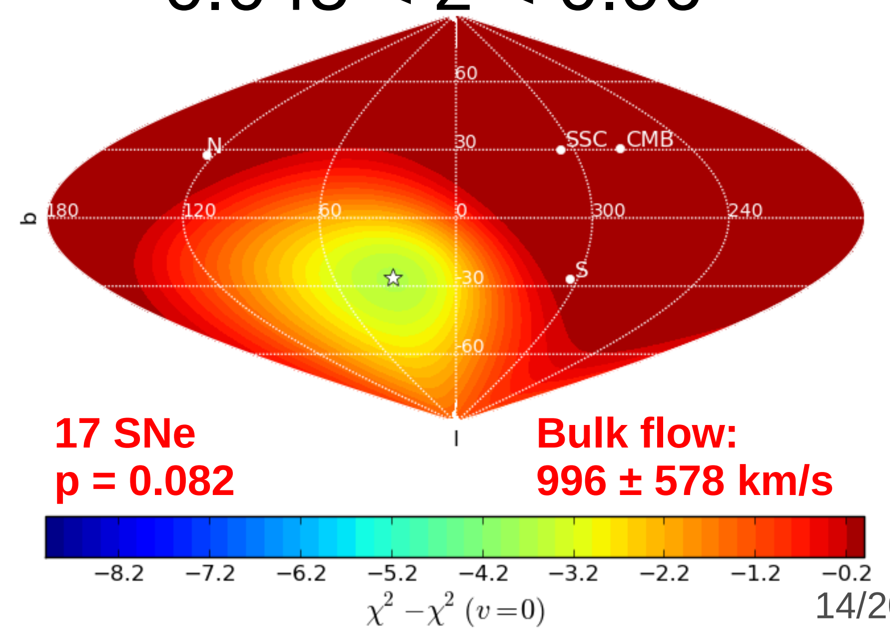



**16 SNe**
**p = 0.281**

**Bulk flow:**
**473 ± 458 km/s**

- **In the Union data there is an (insignificant) “turnaround” of the dipole around the SSC**

0.045 < z < 0.06

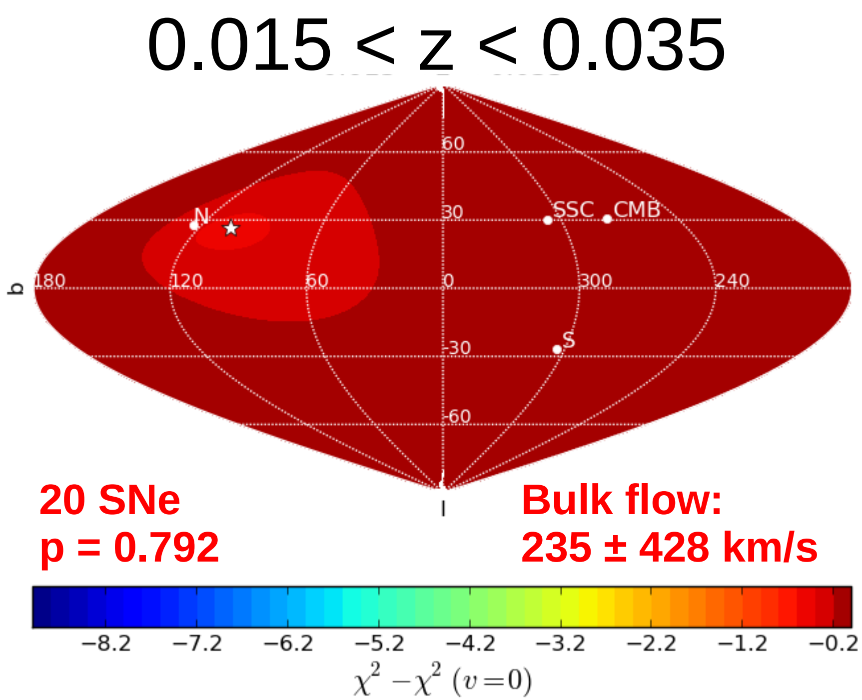


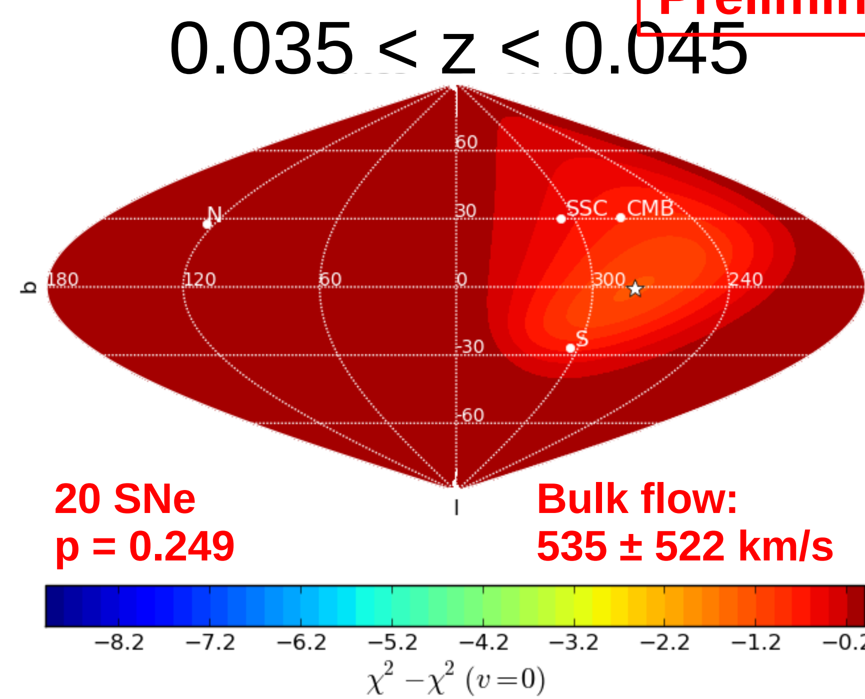

**17 SNe**
**p = 0.082**

**Bulk flow:**
**996 ± 578 km/s**

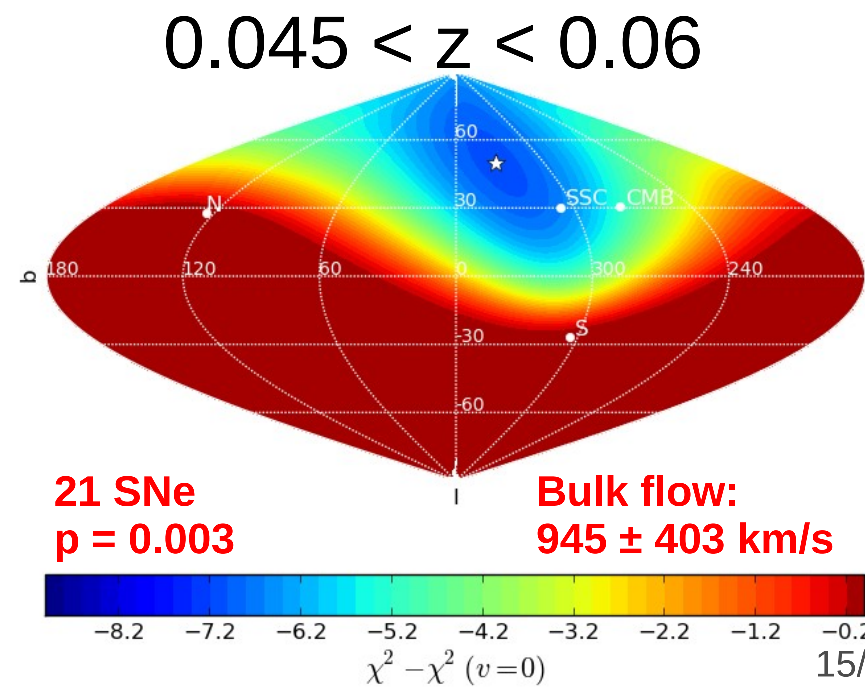
# Nearby Supernova Factory Data

Preliminary



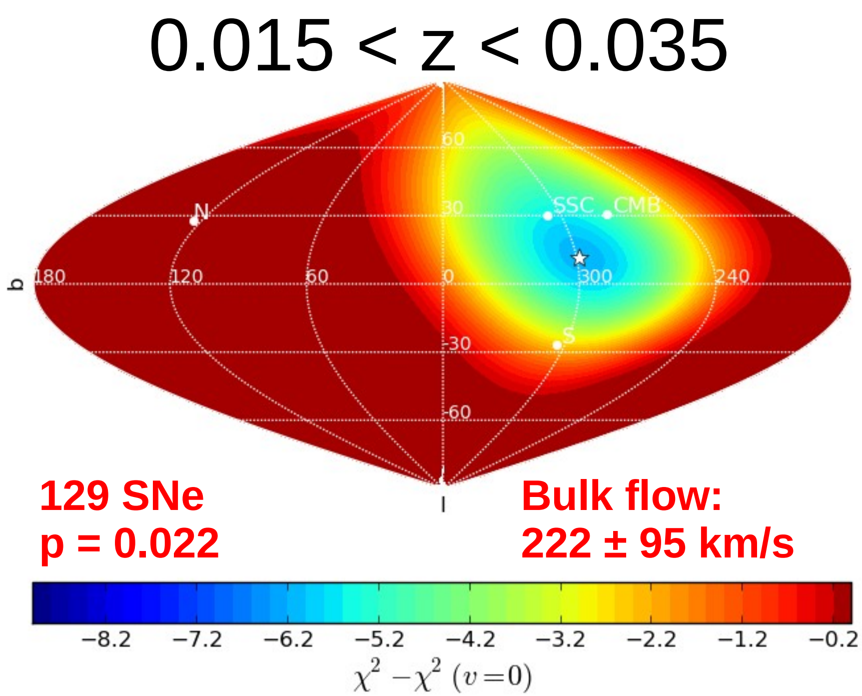



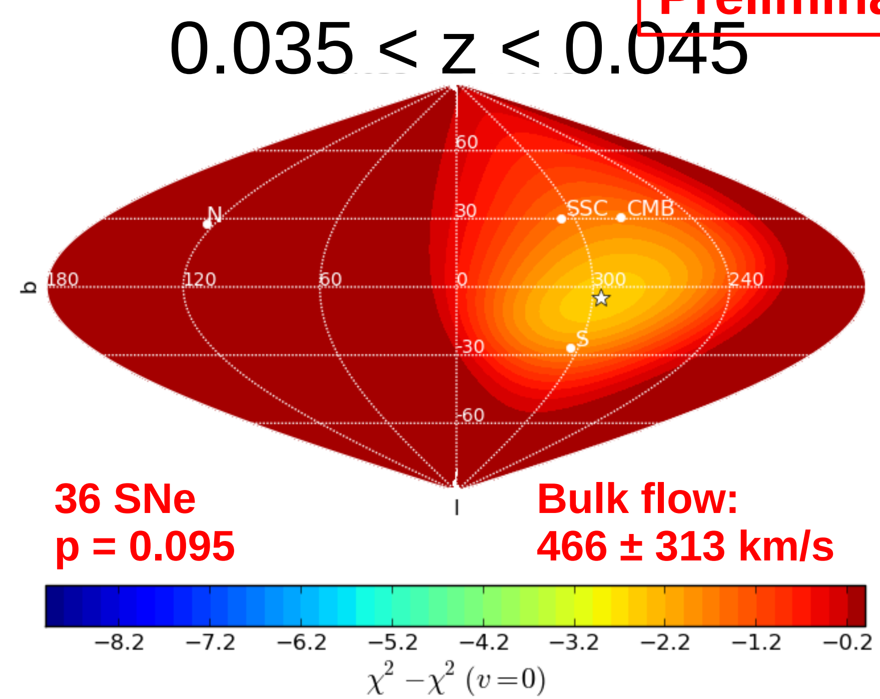

- No turnaround in SNF data. Flow stays in the same direction at the 3σ level!

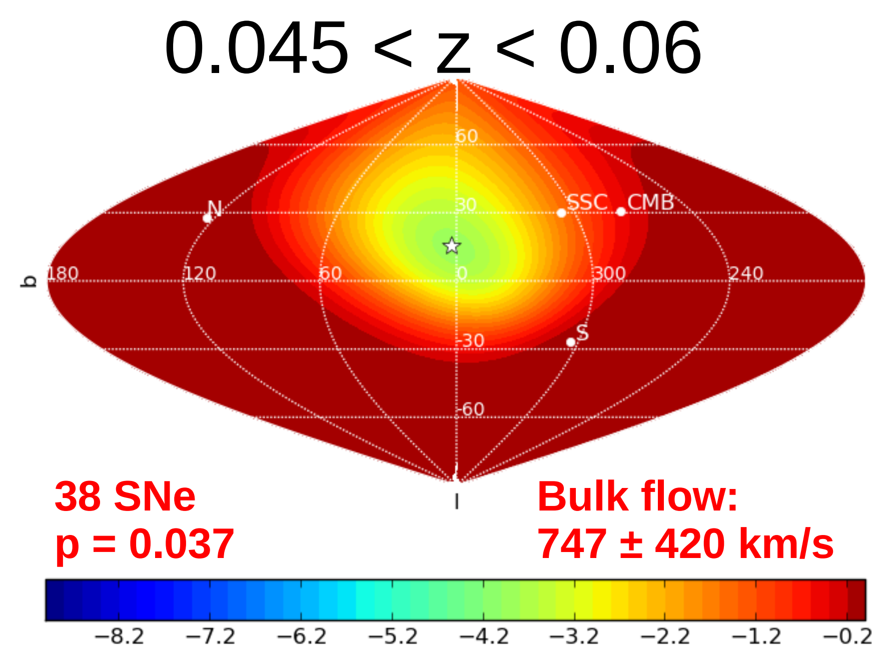


# Combined Data Sets

Preliminary



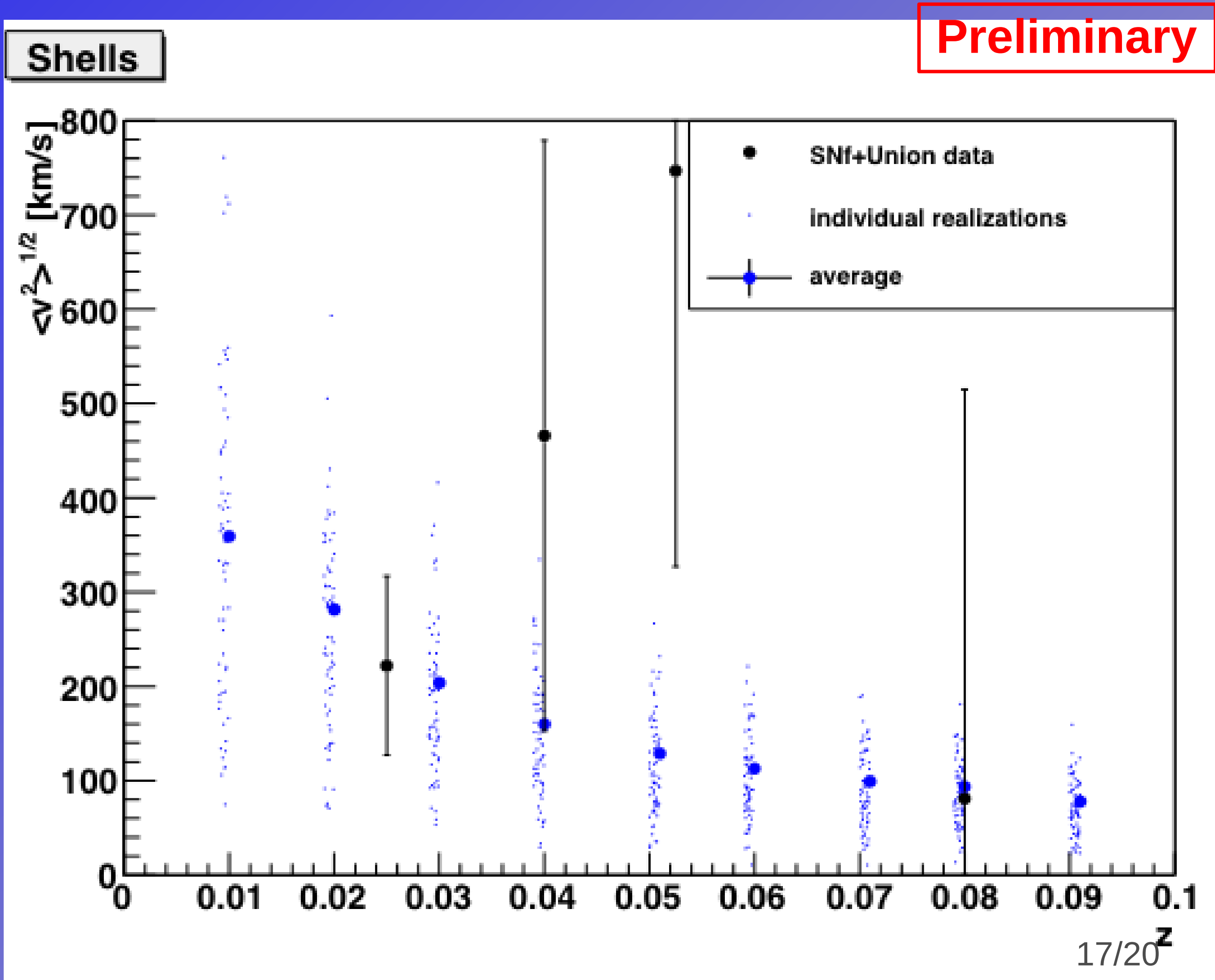

- **We combined Union2.1 and the SNfactory data to 280 SNe at $0.015 < z < 0.1$**
- **No significant turnaround behind SSC**

# ΛCDM Expectation

## (Collaboration with N. Roth and C. Porciani at AIfA, Bonn)

**Using 64 realizations of Large Scale Structure simulations for ΛCDM up to z = 0.1**

- **Expect bulk flow of 100 km/s at z = 0.1**
- **Measured bulk flow consistent with expectation**



# Gravitational Attractor Picture

**Following Peebles (1993) and Muñoz & Loeb (2008), we assume a simple spherical overdensity of radius $R_E$ = 50 Mpc.**

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

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

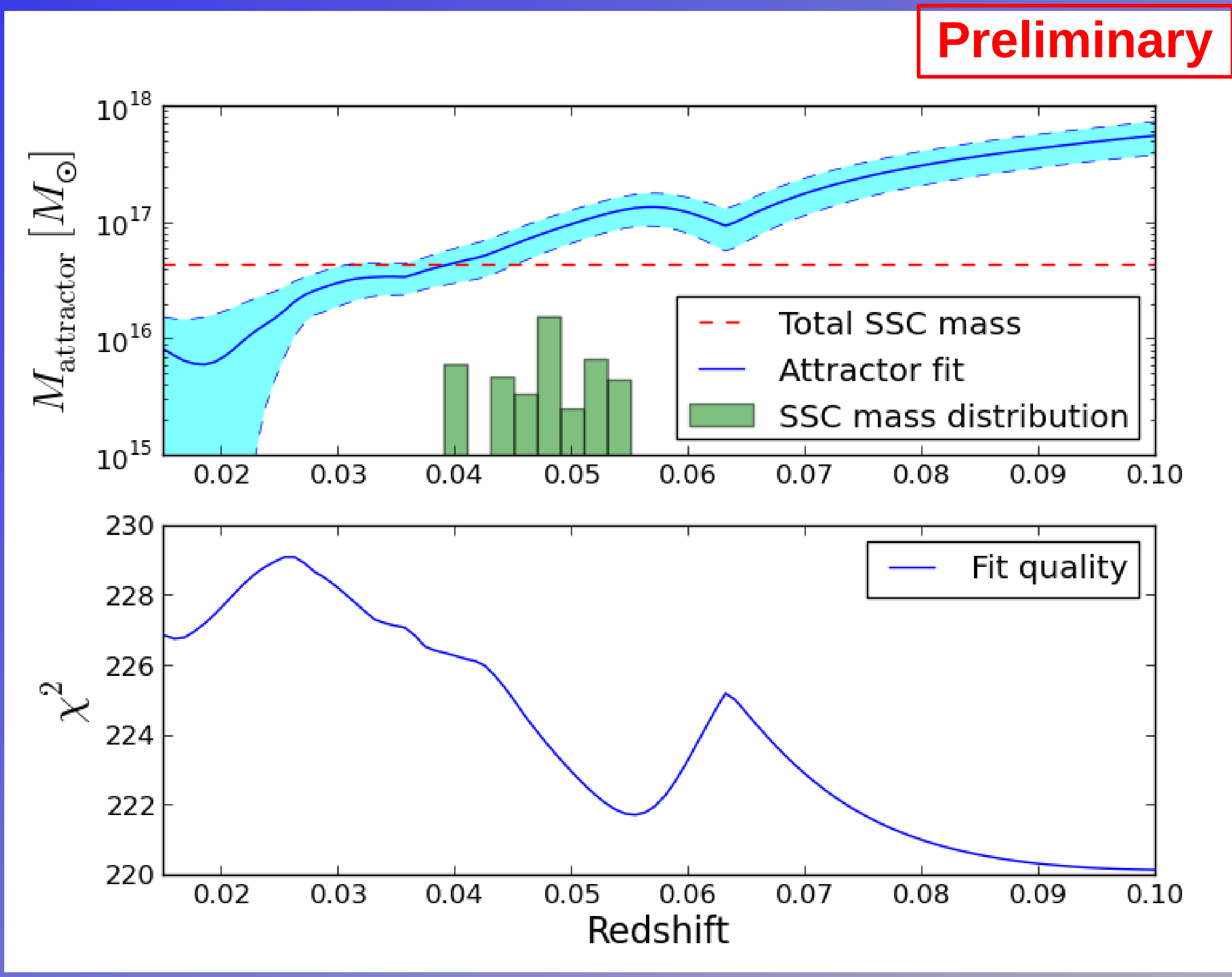
**We determined the mass required to produce the measured peculiar velocities.**

# Reconstructed Attractor Mass

- We assumed a single attractor in the direction of SSC
- Scanned through a range of redshift for the overdensity

- Overdensity at SSC distance would require two to three times its mass

- SSC disfavored at the 2σ level compared to overdensities at higher redshifts



# Conclusion

- We see a 2 – 3σ dipole flow towards SSC and the CMB dipole in the supernova data
- While Union2 suggests a turn around behind SSC, SNfactory does not support this
- The bulk flow seems to extend beyond the Shapley Supercluster
- Main source of the bulk flow remains unresolved