The cosmic web and the Spin of Galaxies

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Linear Tidal Torque theory (TTT) predicts an alignment between angular momentum and shear tensor. [Peebles 1969; White 1984]

Do we see it?

“THE MAIN RESULT”

“The Observational Evidence of Galaxy’s spin alignment with the Shear Tensor on scale larger than 100Mpc.”

Linear Tidal Torque theory (TTT) predicts an alignment between angular momentum and shear tensor. [Peebles 1969; White 1984]

Do we see it?

How good is the TTT approximation?

Where does TTT fail?

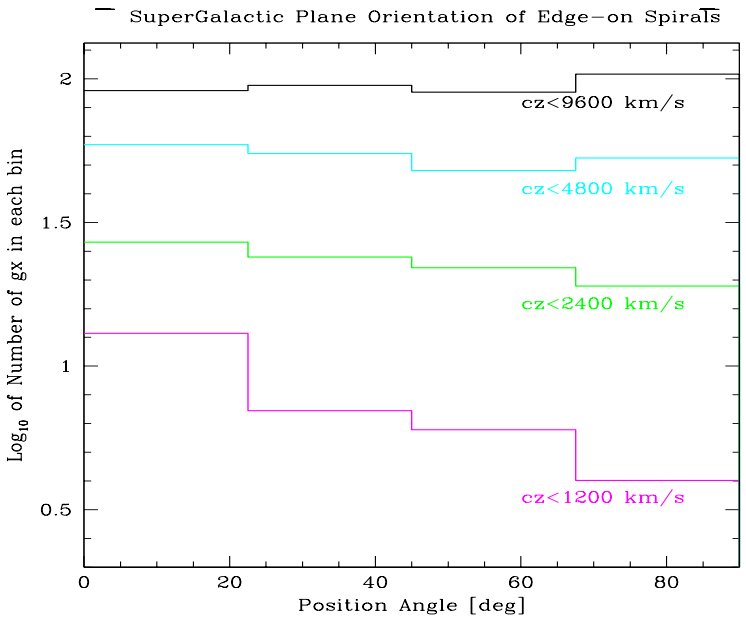
What is the effect of non-linear evolution on Galaxy's spin alignment?

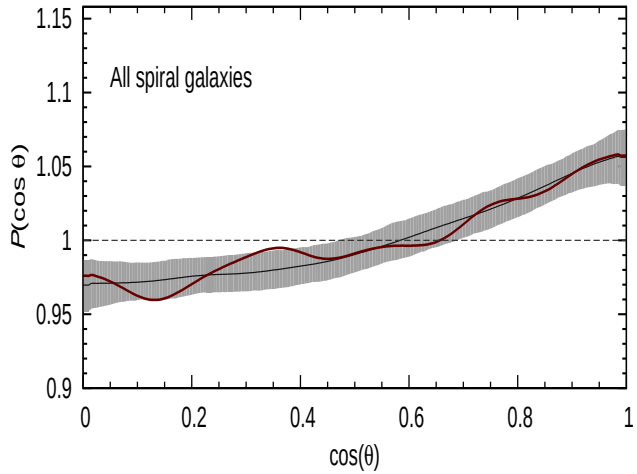
Previous Observational Studies

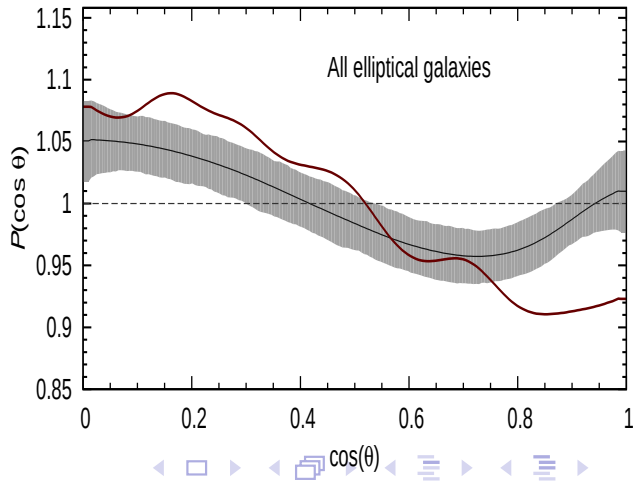
[Tempel et al 2013]

Spin alignment with filaments

[Navarro, Abadi,Steinmetz 2004]

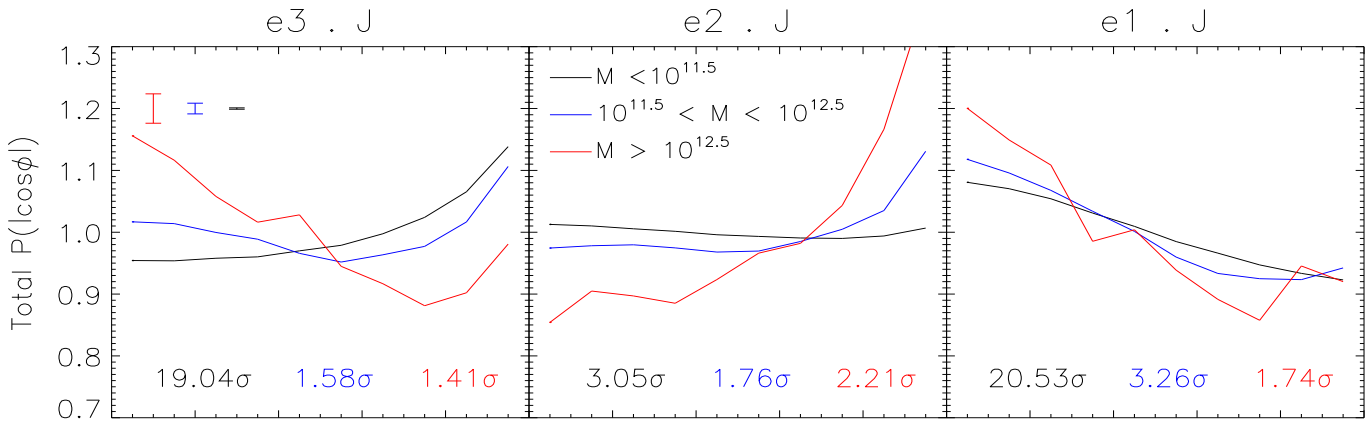






Simulations

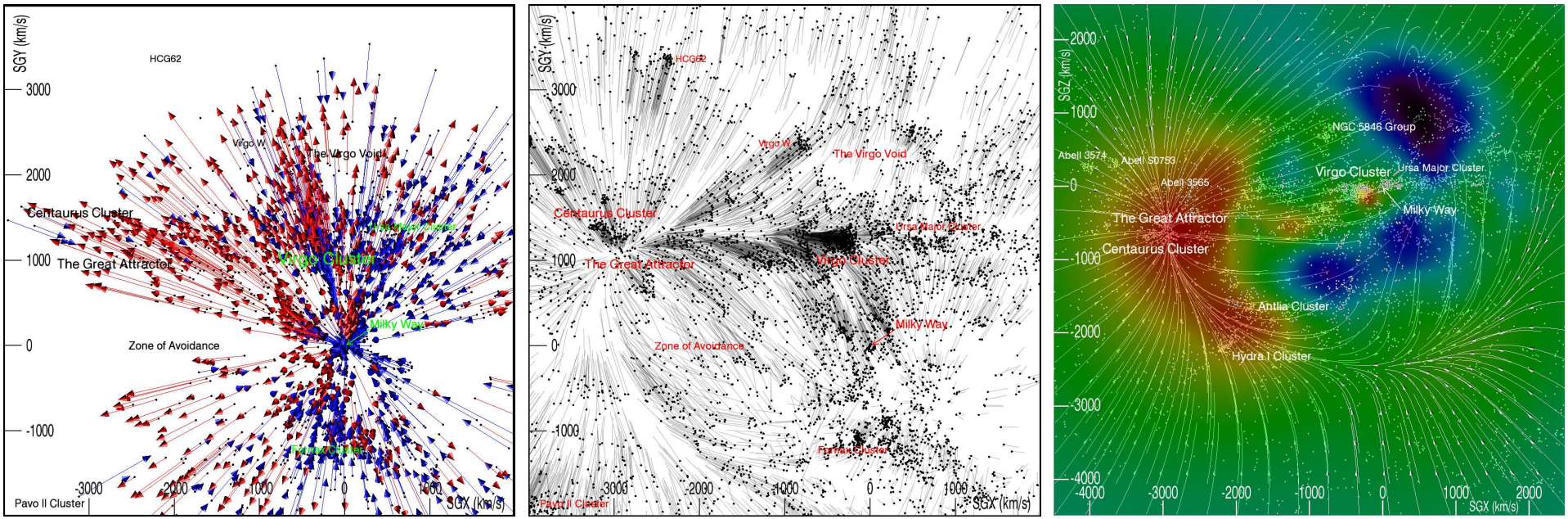
Halo Spin alignment with Shear Tensor [Libeskind et al 2013]



Galaxy Spin alignment with Shear Tensor
in EAGLE simulation
Results in preparation $\longrightarrow$ [Libeskind et al.]

Cosmicflows-2

Reconstruction of Large Scale Structure with Wiener-filter technique



[Courtois et al 2013]

The WF/CRs methodology reconstructs the underlying density and 3D velocity fields out to distance exceeding 100Mpc.

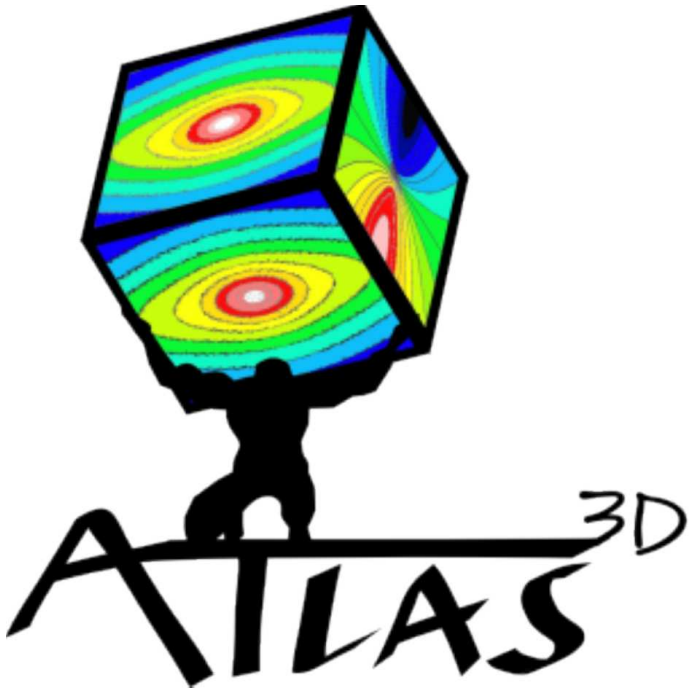
CF2 acts as a backbone on which we test Tidal Torque Theory and alignments

Shear Tensor can be obtained from the reconstructed peculiar velocity field as

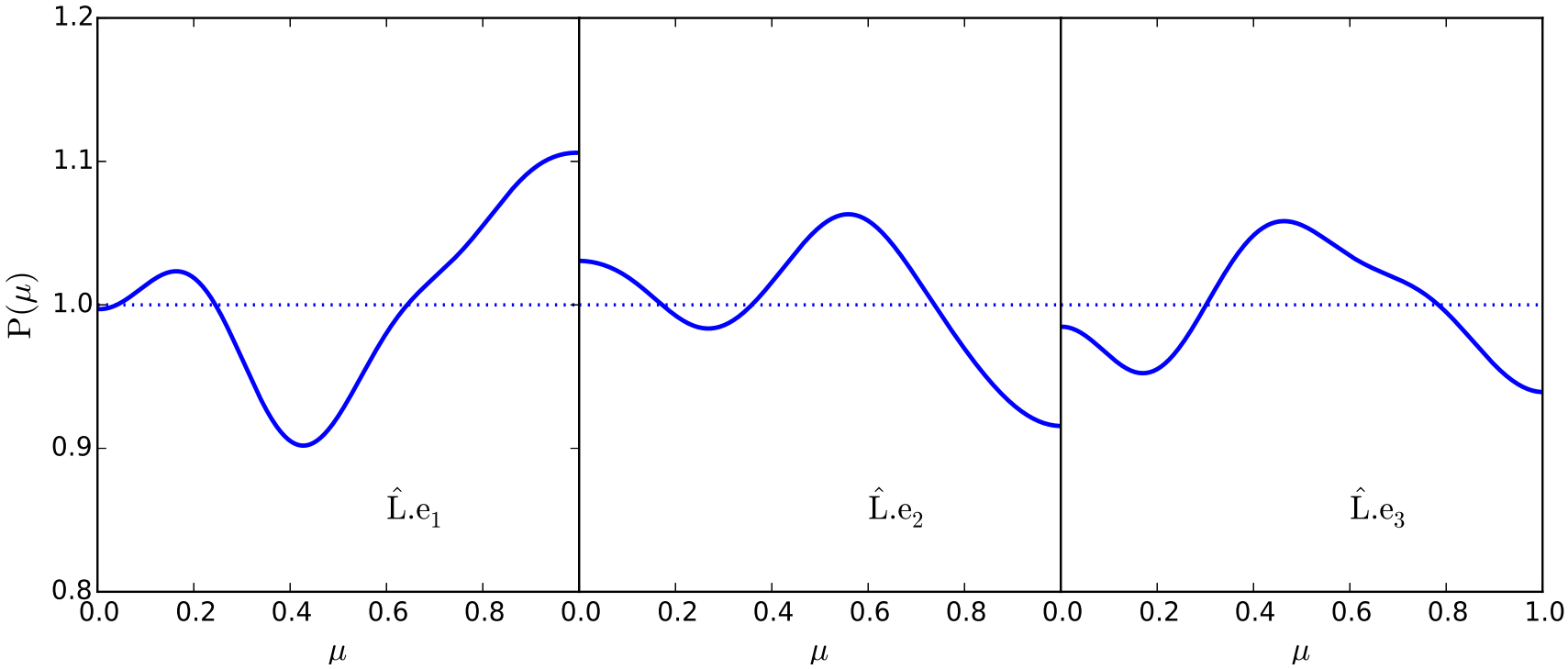
$$\Sigma_{\alpha\beta} = -\frac{1}{2H_0}\left(\frac{\partial v_\alpha}{\partial r_\beta} + \frac{\partial v_\beta}{\partial r_\alpha}\right),$$

Eigen values of shear tensor are $\lambda_1 > \lambda_2 > \lambda_3$
and the corresponding eigenvectors are $e_1, e_2,$ and e_3.

DATA

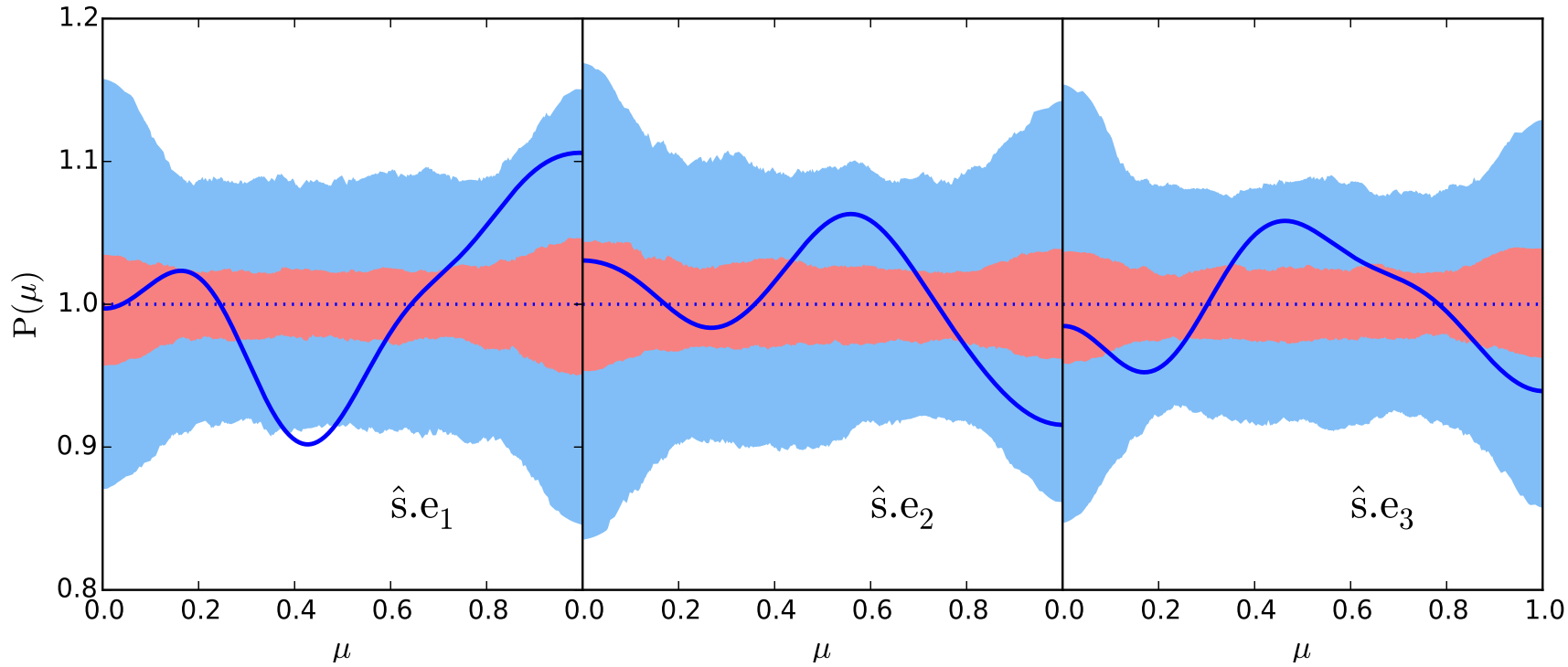


- Number of galaxies = 260 (Photometric data)
- Early-type galaxies
- within or around VIRGO cluster
- Galaxy Stellar Mass, $M_* \gtrsim 6 \times 10^9$ $M_\odot$



$\mu \equiv |\cos(\hat{s}.\hat{e}_i)|$, $\hat{s}$ is the rotation axis.

$\mu \in [0, 1]$



with 2σ error bars

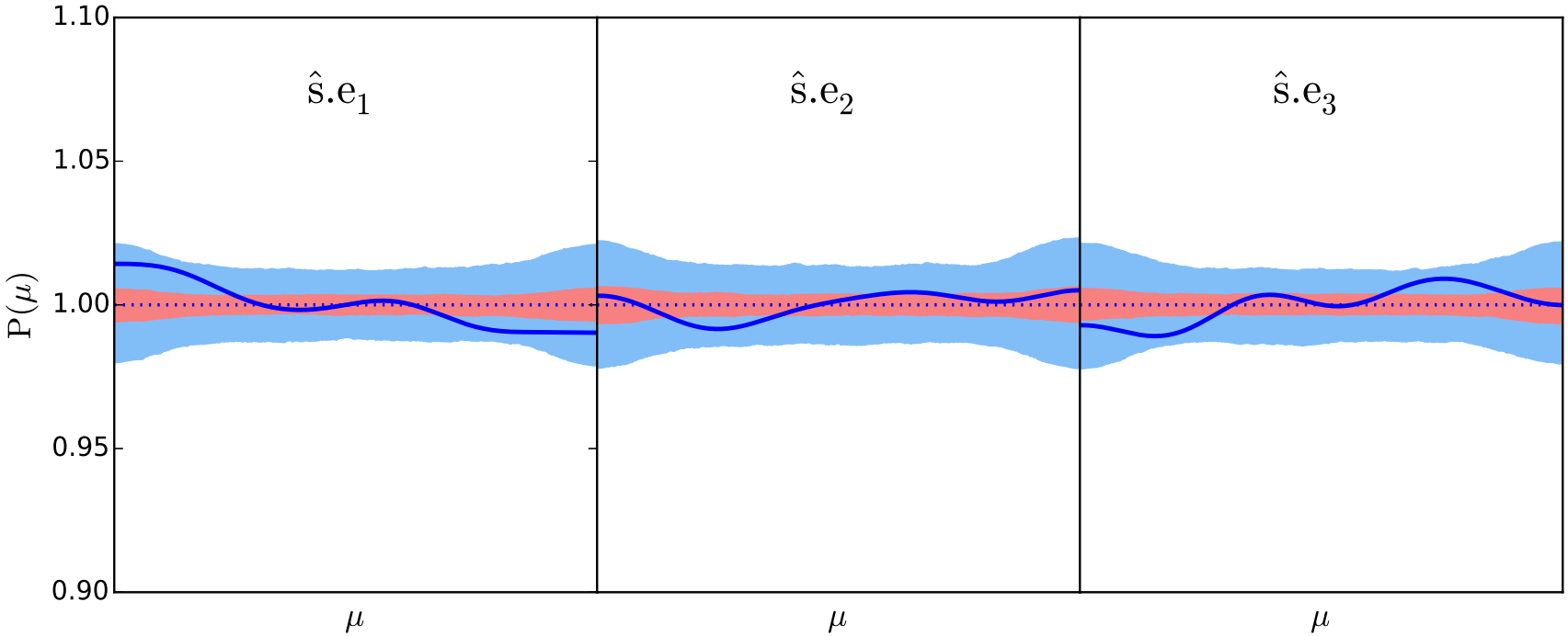
$$\mu \equiv \left|\cos\left(\hat{s}.\hat{e}_i\right)\right|$$

DATA

2MASS
Redshift Survey
(2MRS)

- Number of galaxies (Sub-sample) = $19,438$
- Elliptical galaxies - 8334
- Spiral galaxies - 11104

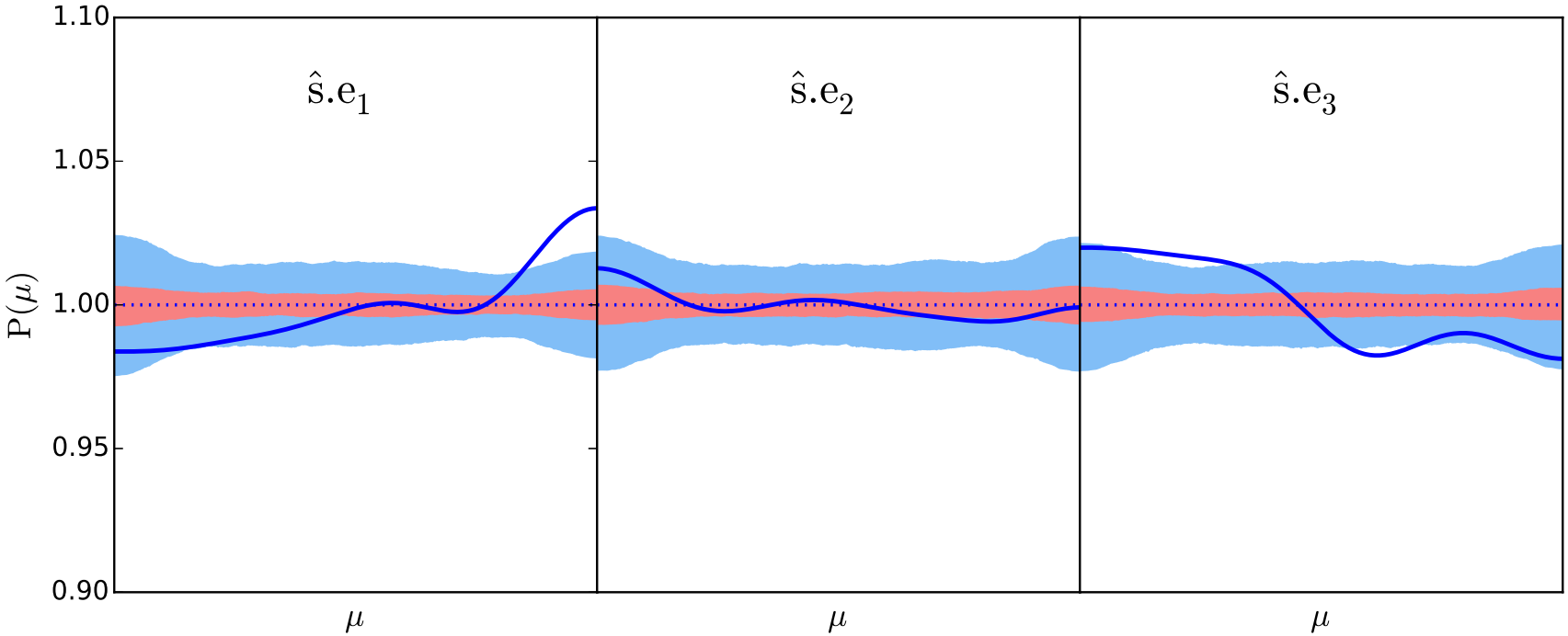
2MRS (Spiral Galaxies)



No signal!

$$\mu \equiv \left|\cos(\hat{s}.\hat{e}_i)\right|$$

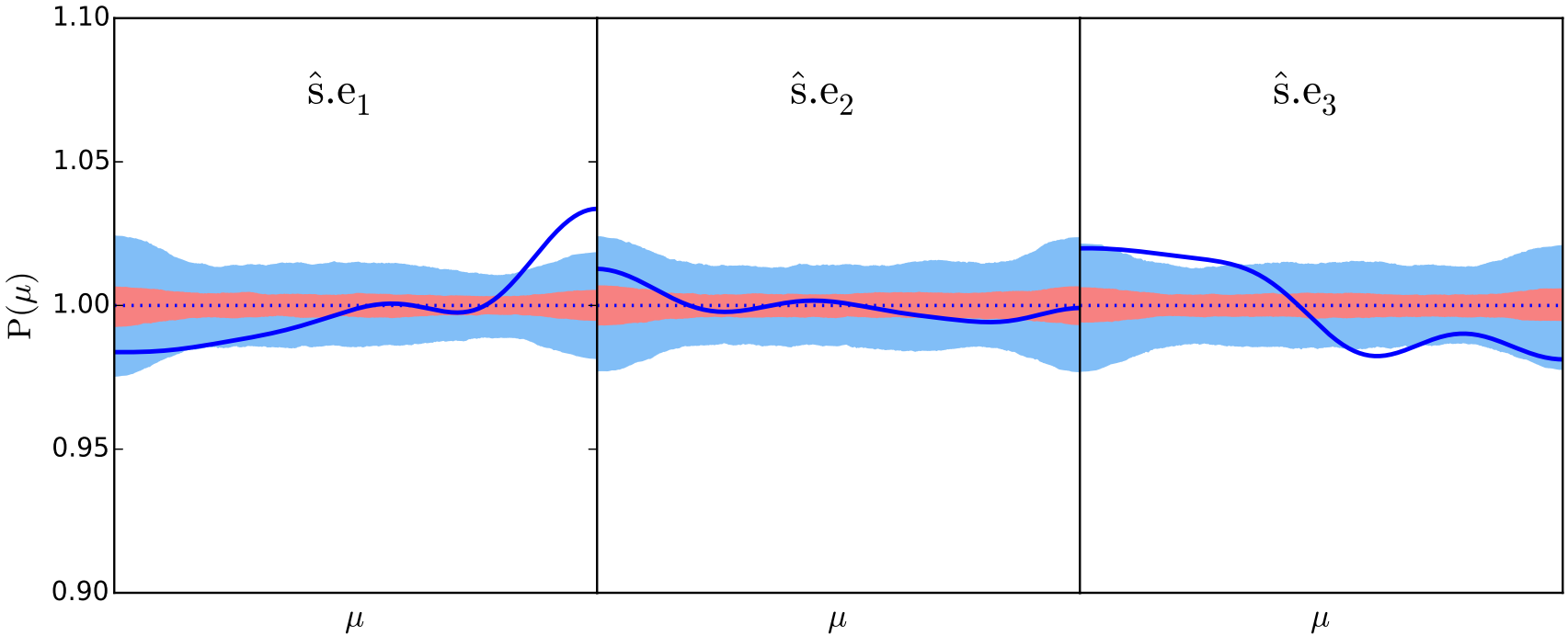
2MRS (Elliptical Galaxies)



Weak Signal!

$$\mu \equiv |\cos(\hat{s}.\hat{e}_i)|$$

2MRS (Elliptical Galaxies)



Weak Signal!

Can we do something?

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Weak Signal!

1. It's physics!

Weak Signal!

Can we do something?

1. It's physics!
2. It's CF2 sampling!

Cosmicflows-2 enables the reconstruction of Large Scale Structure out to distance exceeding 100 Mpc.

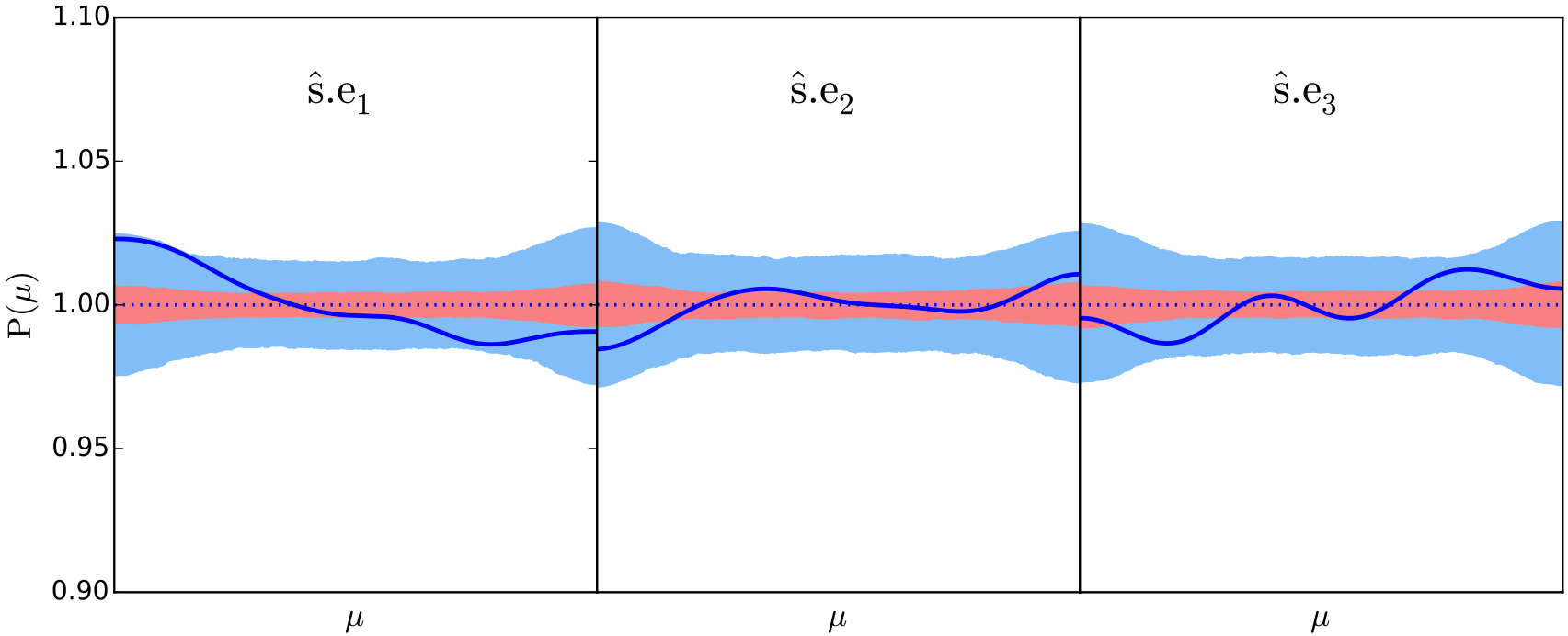
We select only those galaxies from 2MRS sample whose distances are less than 100 Mpc.

2MRS (distances < 100Mpc)

Number of Galaxies - 11812

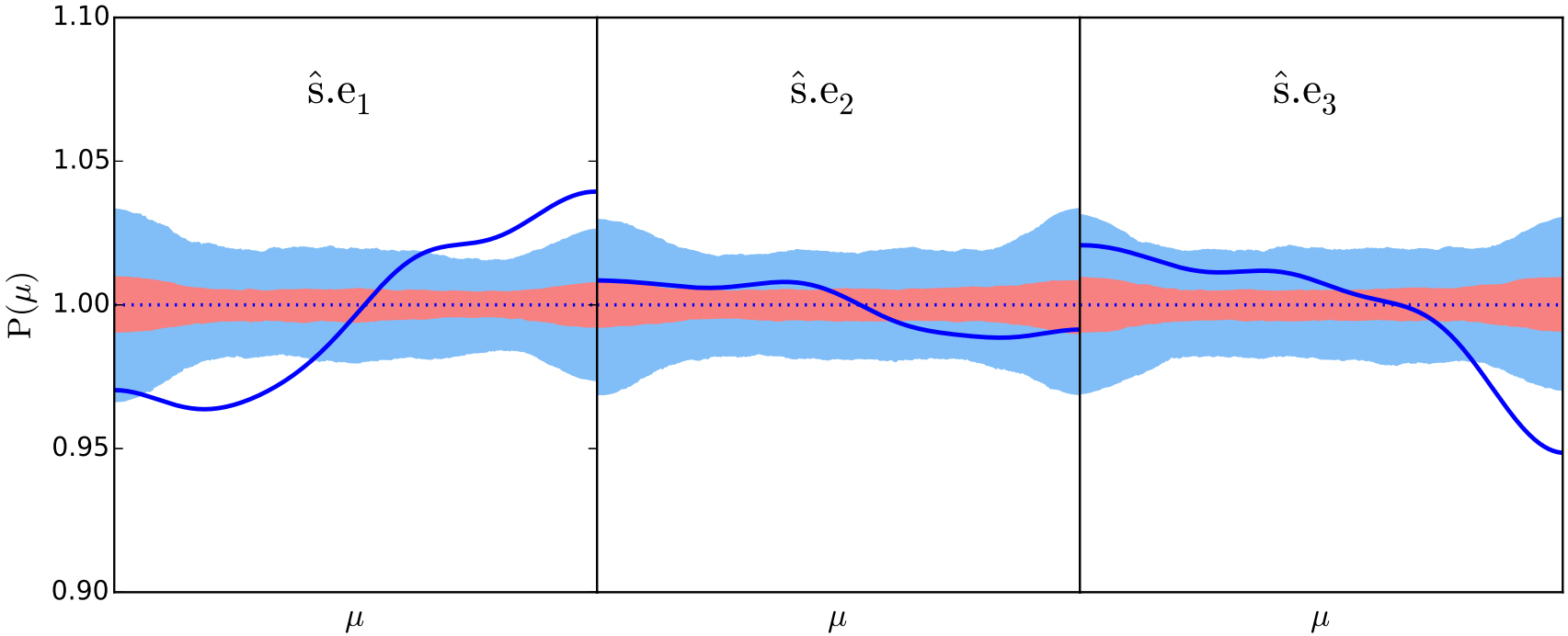
Elliptical Galaxies - 4598
Spiral Galaxies - 7224

2MRS (distances < 100Mpc) (Spiral Galaxies)



$$\mu \equiv |\cos(\hat{s}.\hat{e}_i)|$$

2MRS (distances < 100Mpc) (Elliptical Galaxies)



2σ Signal but....

$$\mu \equiv |\cos(\hat{s}.\hat{e}_i)|$$

Next...

2MRS ∩ CF2

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Sub-Sample $\longrightarrow$ Choose only those Galaxies which are used in Cosmicflows-2

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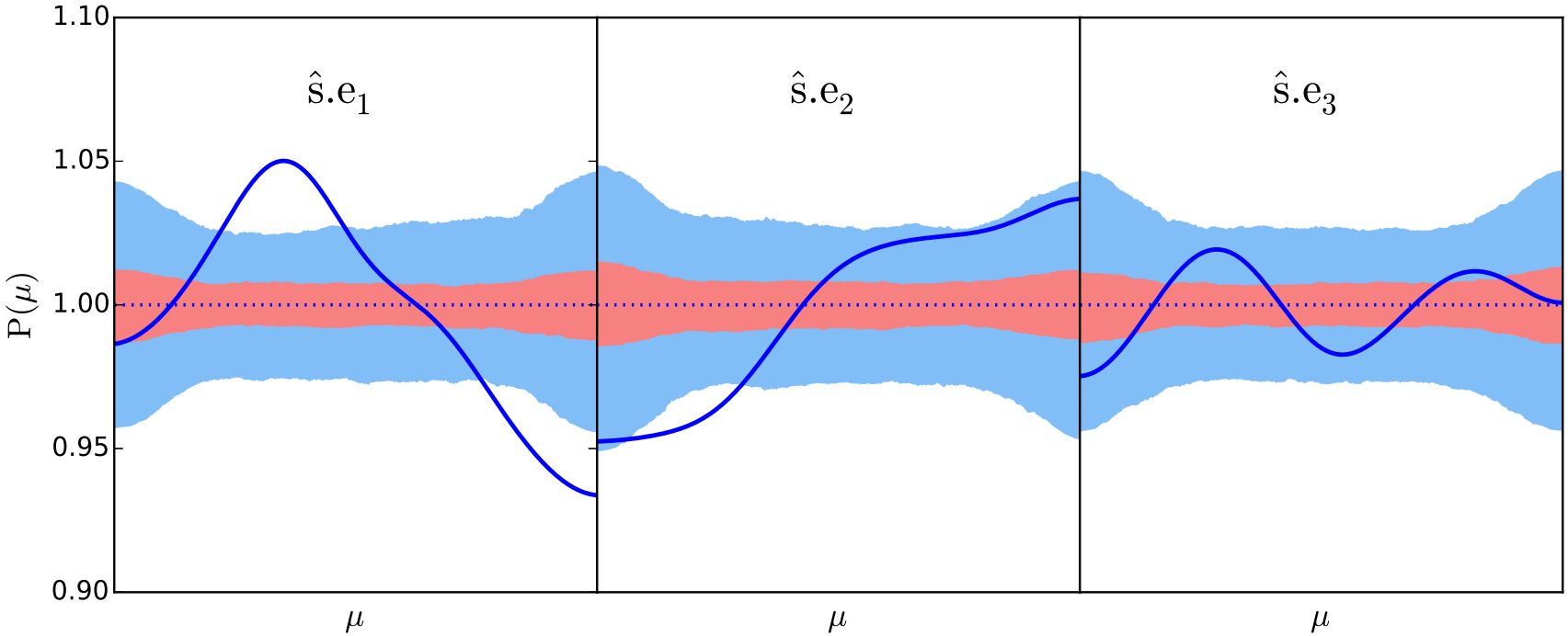
New Sample - 3616

Elliptical Galaxies - 929
Spiral Galaxies - 2687

2MRS ∩ CF2 (Spiral Galaxies)



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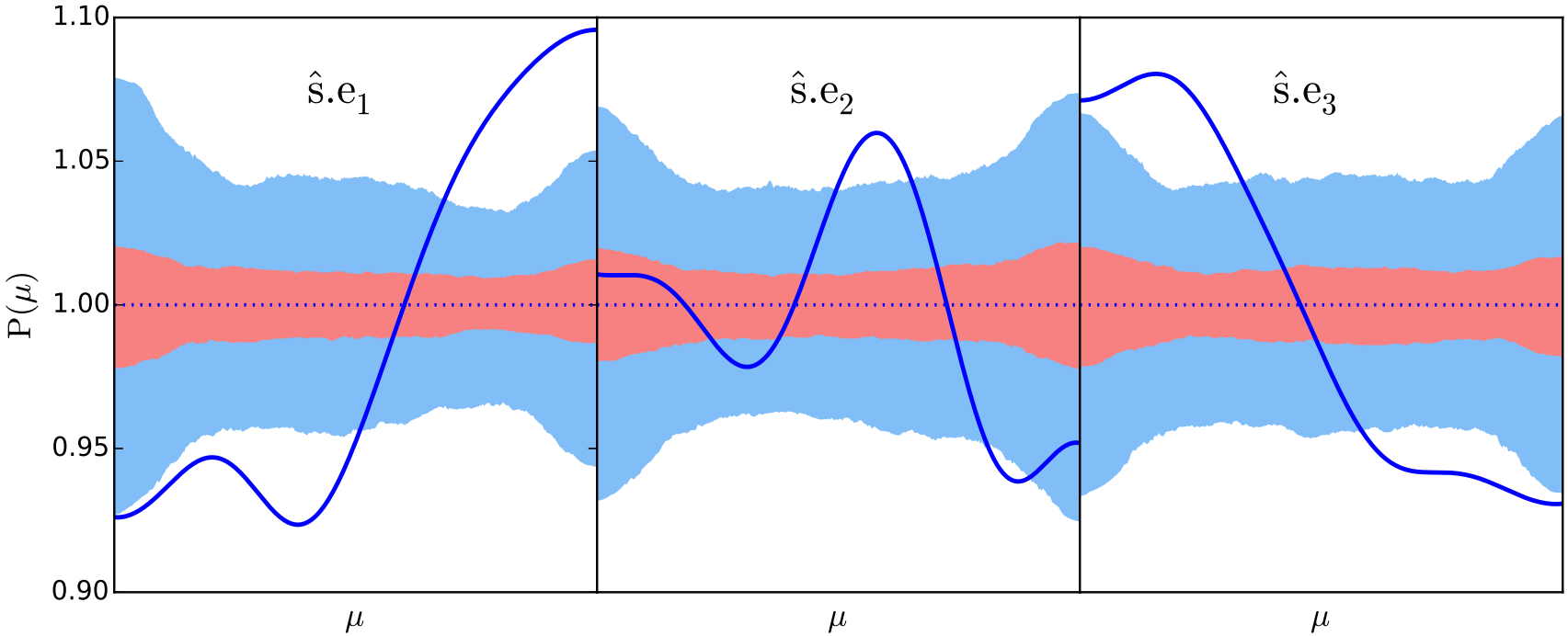
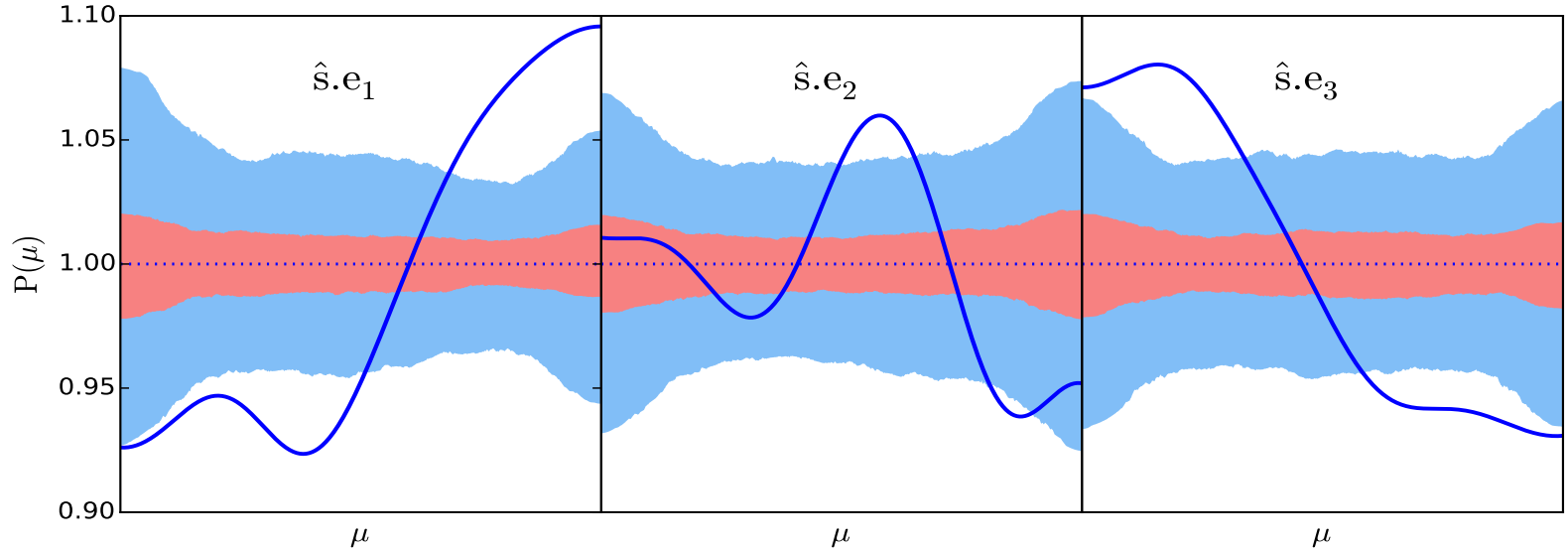
2MRS ∩ CF2 (Elliptical Galaxies)

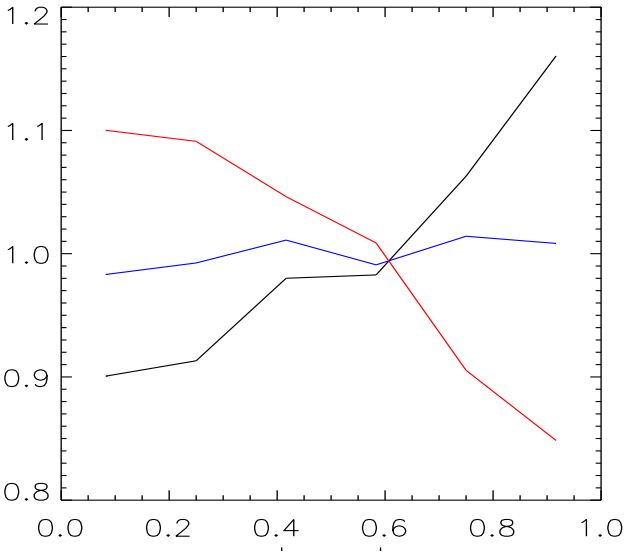


GOOD SIGNAL!

$$\mu \equiv |\cos(\hat{s}.\hat{e}_i)|$$

2MRS ∩ CF2 (Elliptical Galaxies)





$$\mu \equiv e_1.\hat{j}(< 30\mathrm{kpc})$$
$$\mu \equiv e_2.\hat{j}(< 30\mathrm{kpc})$$
$$\mu \equiv e_3.\hat{j}(< 30\mathrm{kpc})$$

[Libeskind et al. in prep.](EAGLE)

Predicting future

$\cos(e_1.\mathrm{J_{MW}}) = 0.22$ (Milky Way)

$\cos(e_1.\mathrm{J_{M31}}) = 0.63$ (Andromeda)

MW-M31 orbital plane is roughly in $(e_2 - e_3)$ plane.

$\cos(e_1.\mathrm{J_{LG}}) = 0.95$ [van der Marel et al. 2012]

$\Rightarrow$ **In few billion years, Spin will be aligned with e_1.**

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$\Rightarrow$ **which is in agreement with our result!**

Conclusions

- No significant alignmets in ATLAS^{3D} and weak alignment in 2MRS sample
- 2MRS (distances < 100Mpc) also shows significant alignment with resconstructed cosmic web but not as strong as 2MRS $\cap$ CF2 sub-sample - Need better sampling?

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- No significant alignmets in ATLAS^{3D} dataset and weak alignment in 2MRS sample
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- Elliptical Galaxies show significant alignment with e_1 and e_3 in 2MRS $\cap$ CF2 - **Reconstruction works pretty well!**

THANK YOU!