

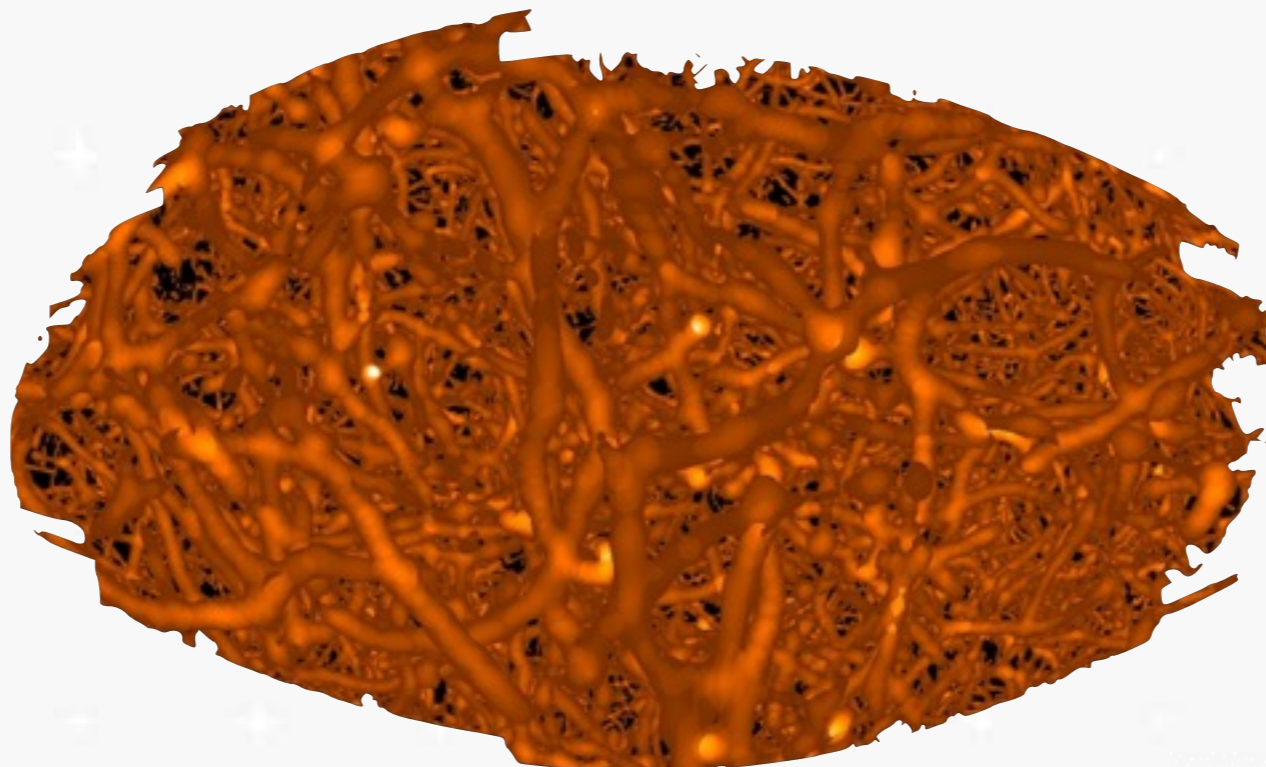


Cosmic web and galaxy filaments

Elmo Tempel

Leibniz-Institut für Astrophysik Potsdam (AIP), Germany

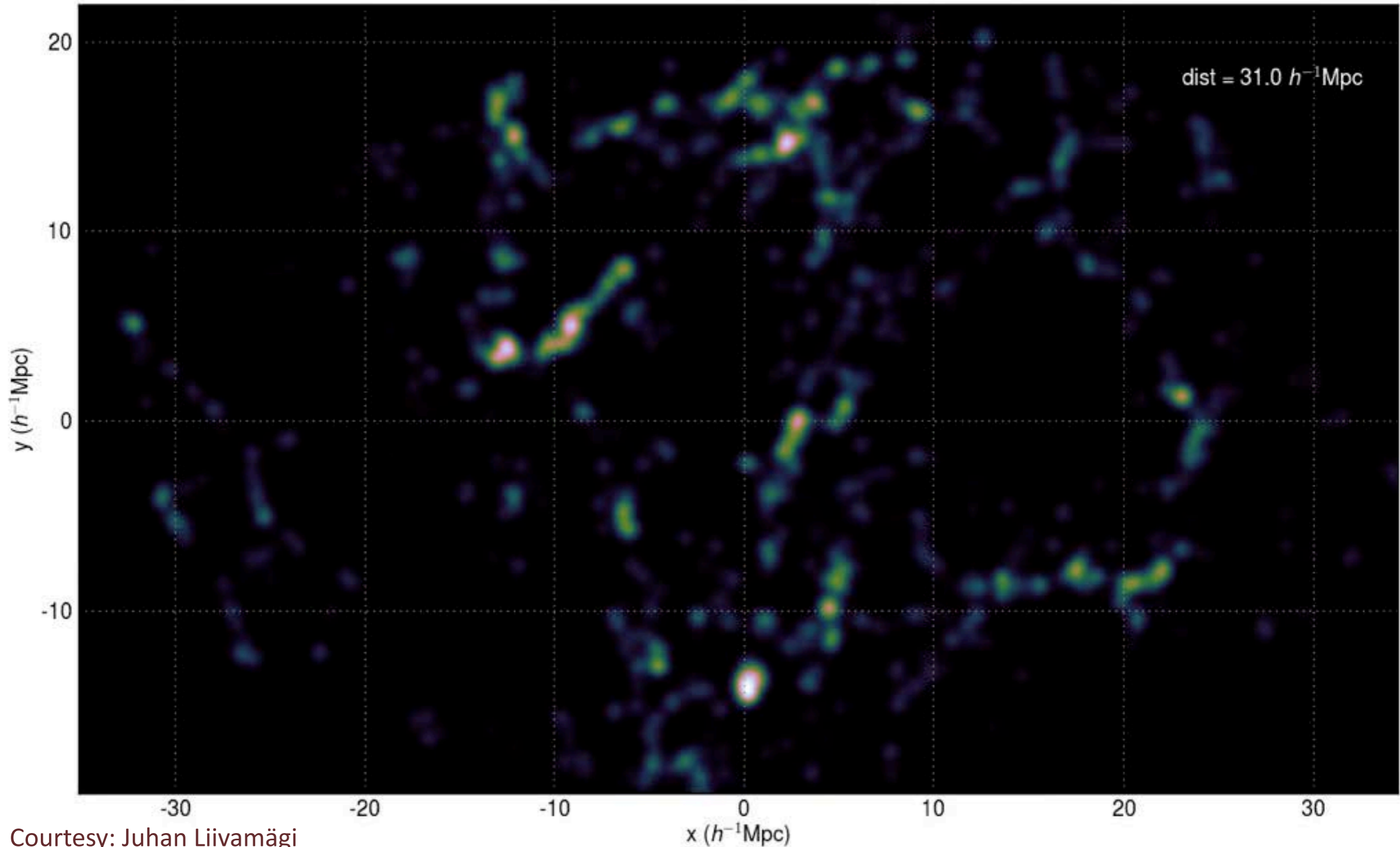
Tartu Observatory, Estonia



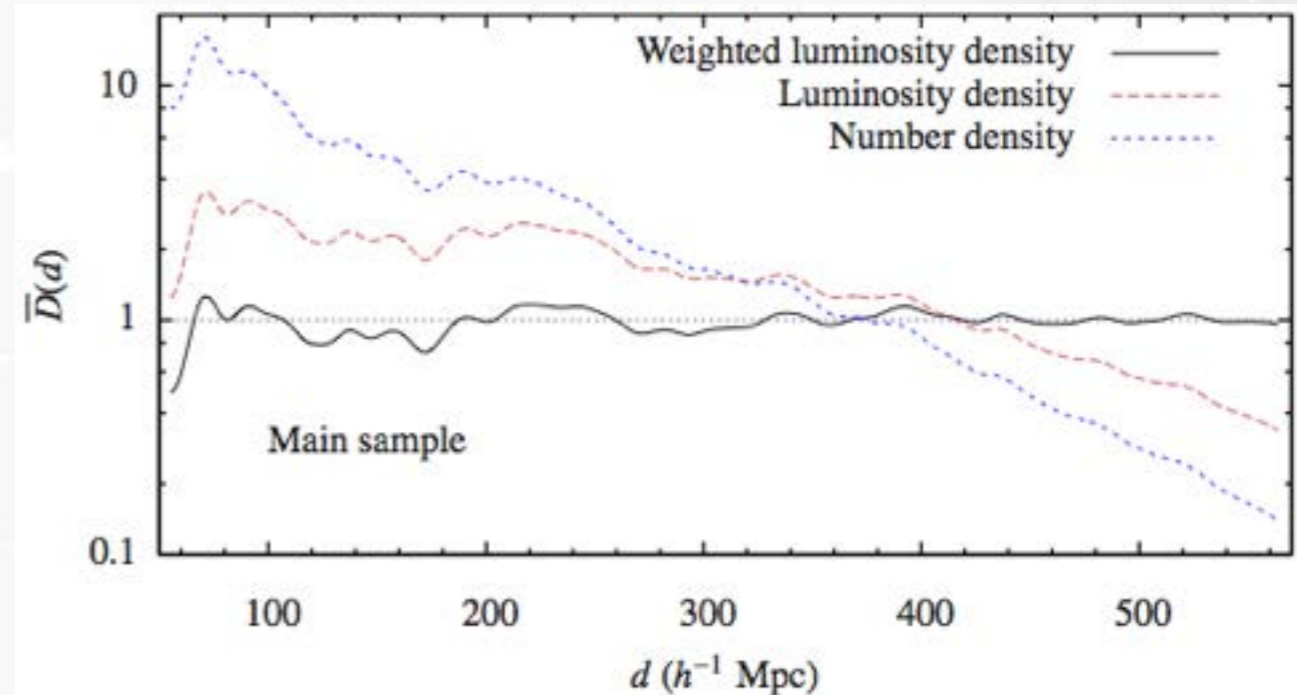
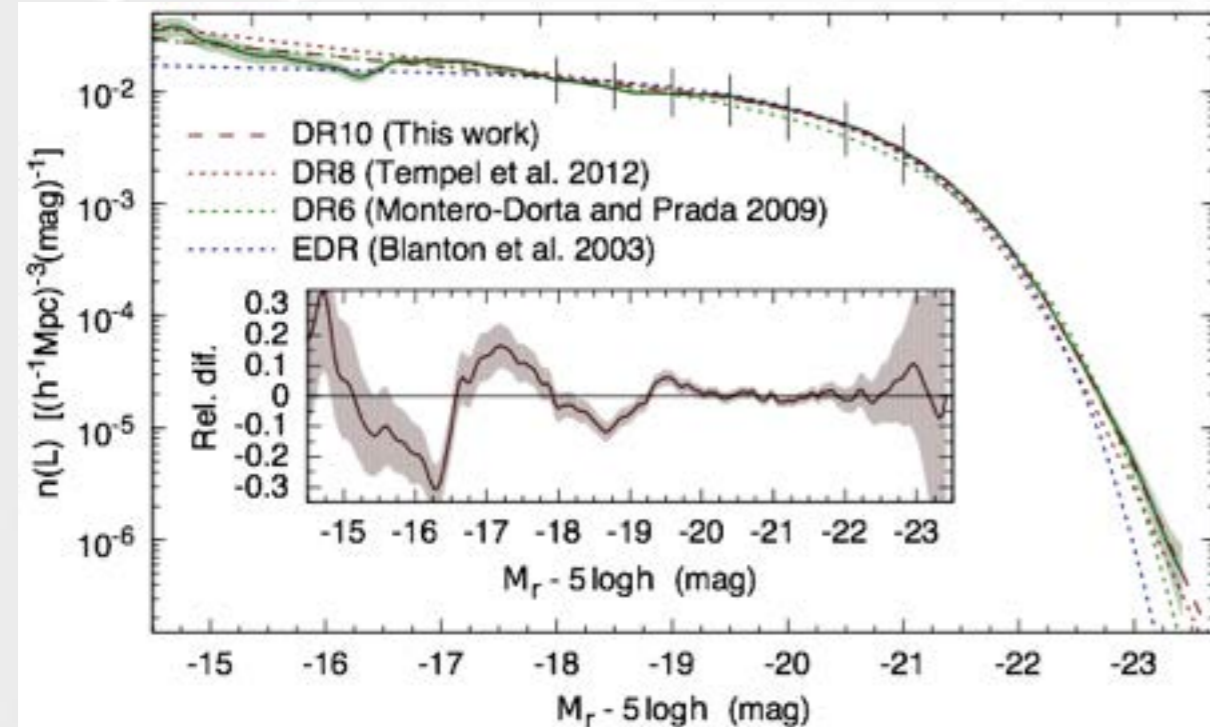
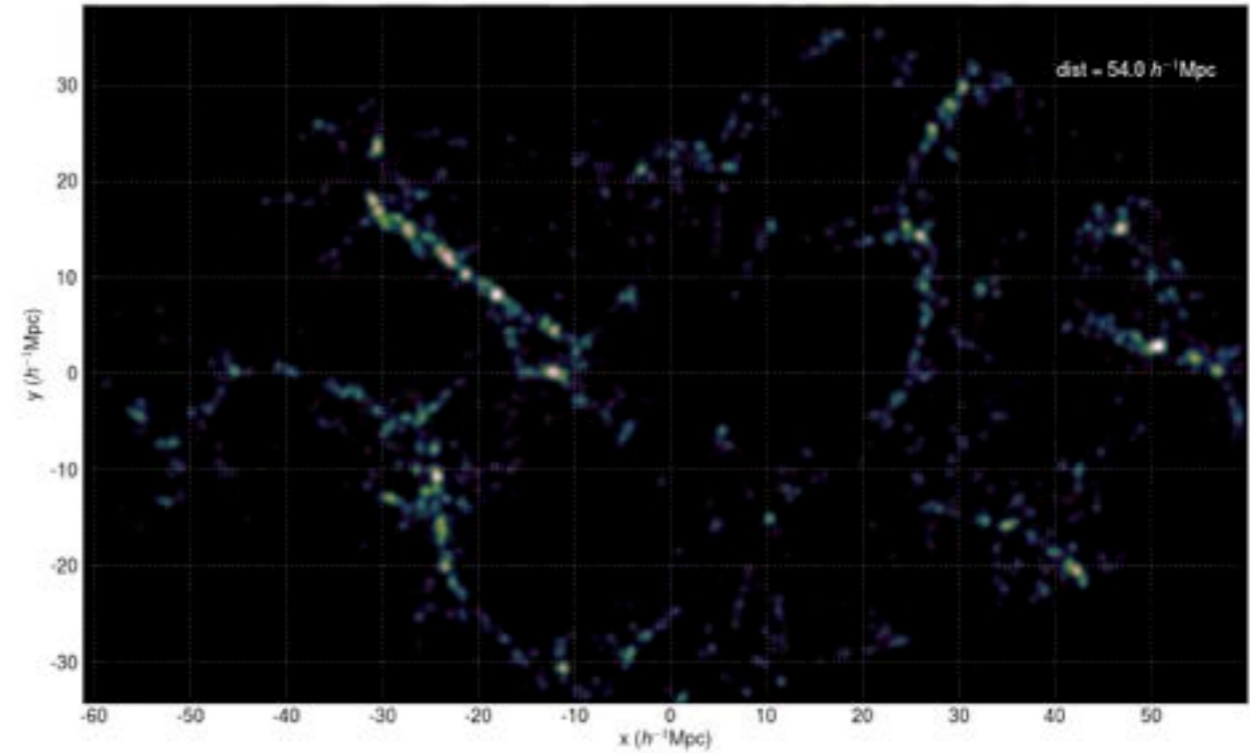
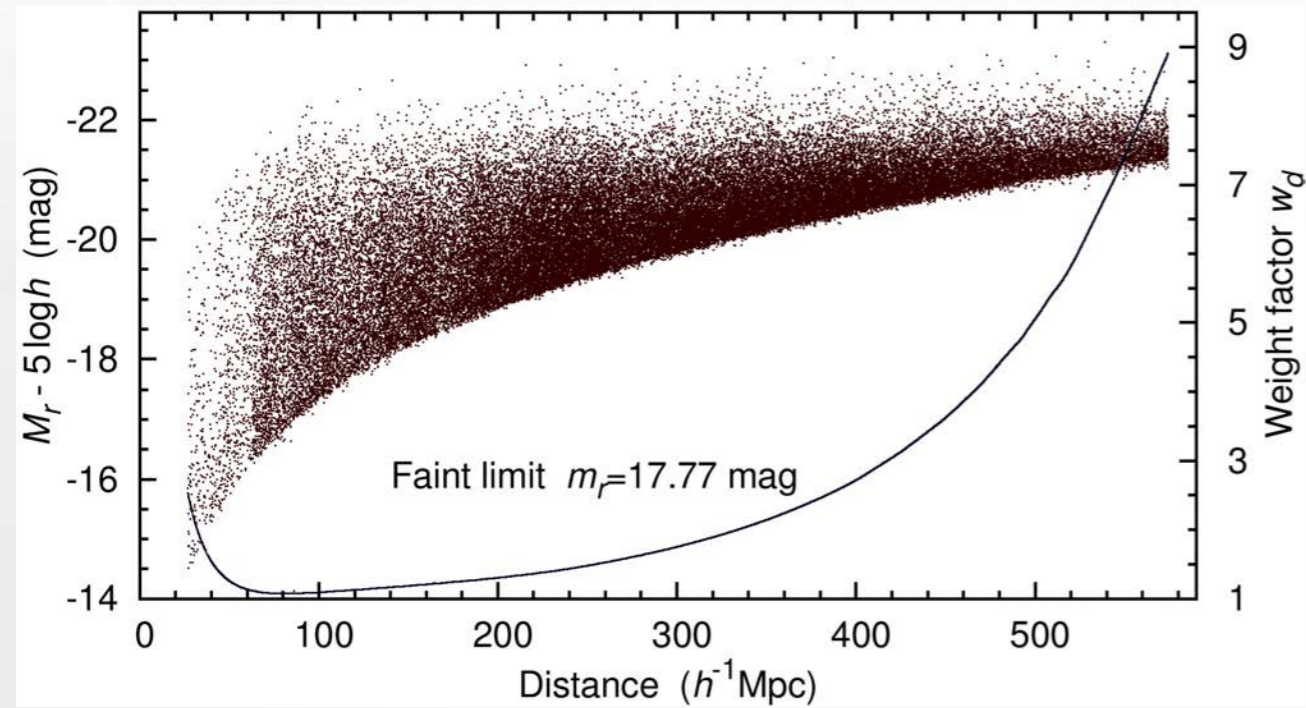
KIAS 2016



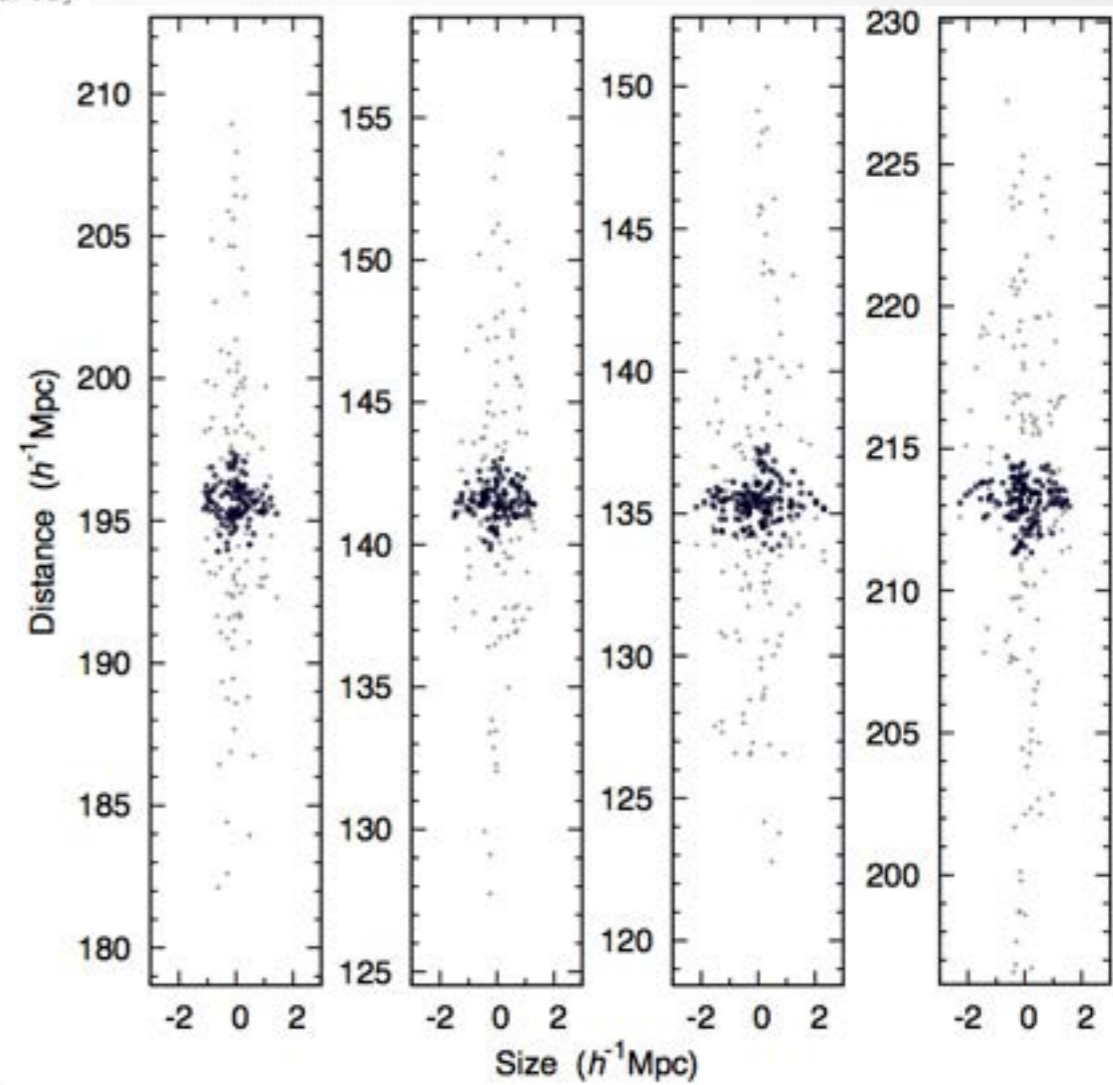
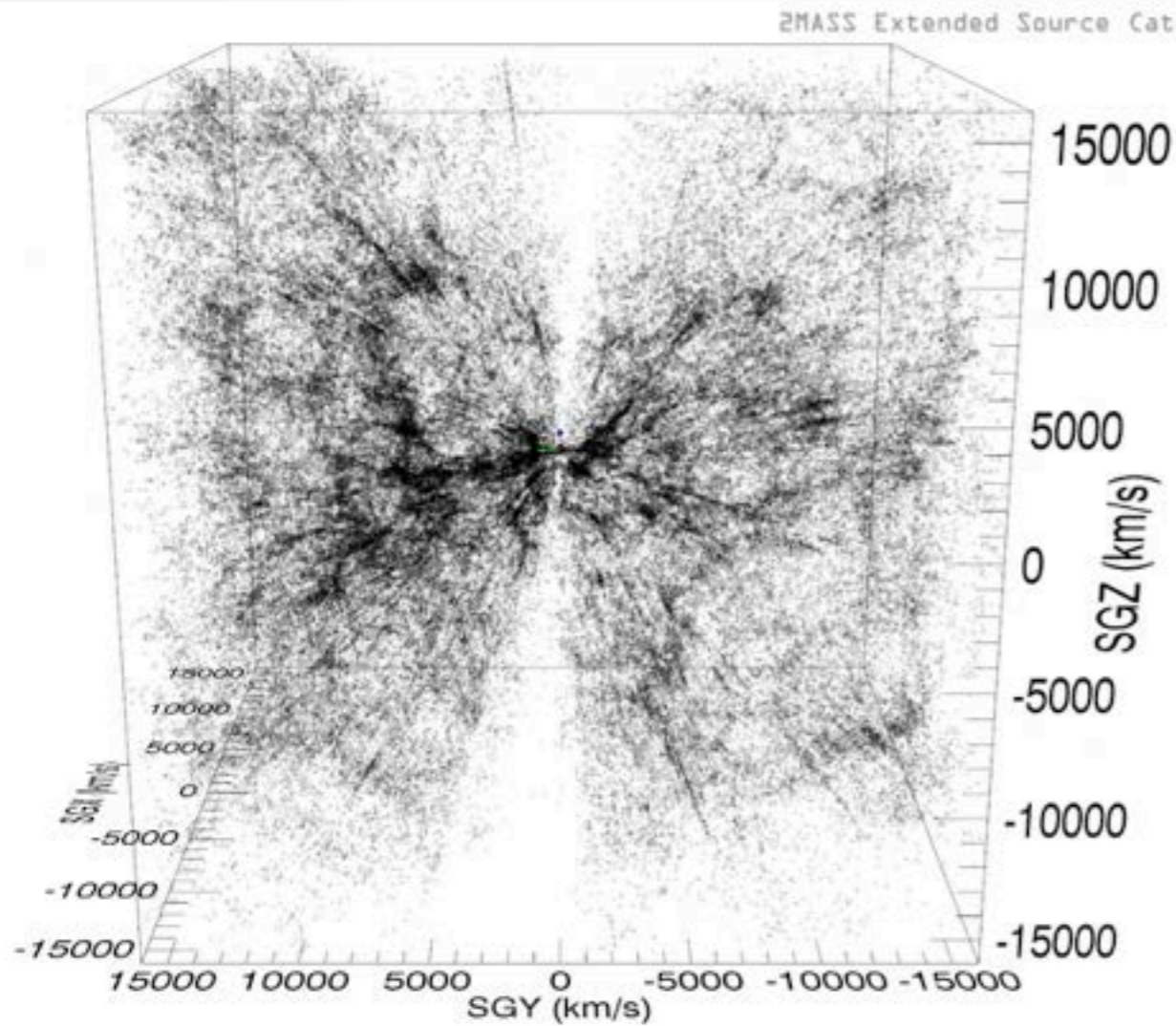
Luminosity density field in the SDSS



Observations: selection effects



Observations: redshift space distortions



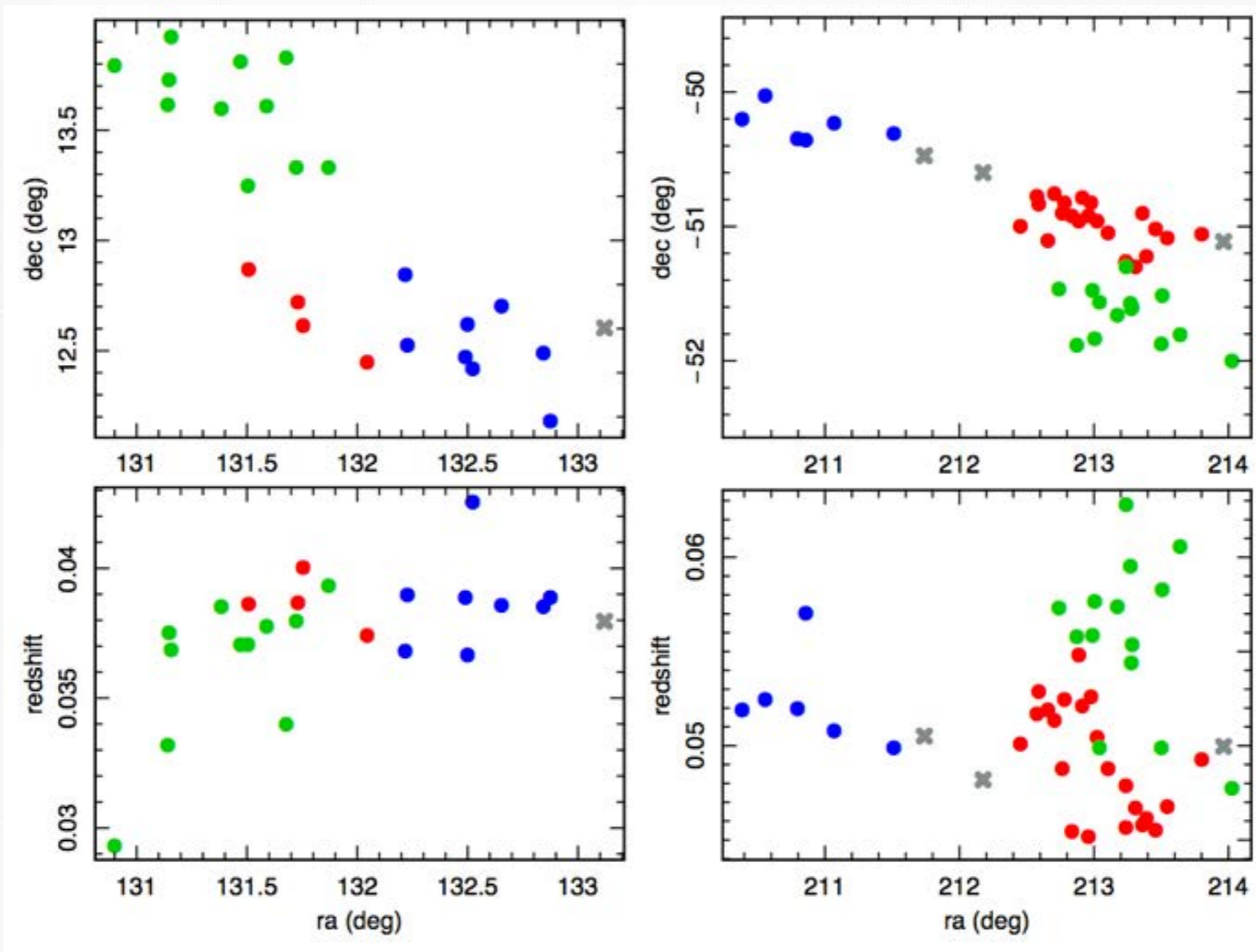
Courtesy: Tully et al. 2014, Nature, 513, 71

Tempel et al. (2012,2014,2016)

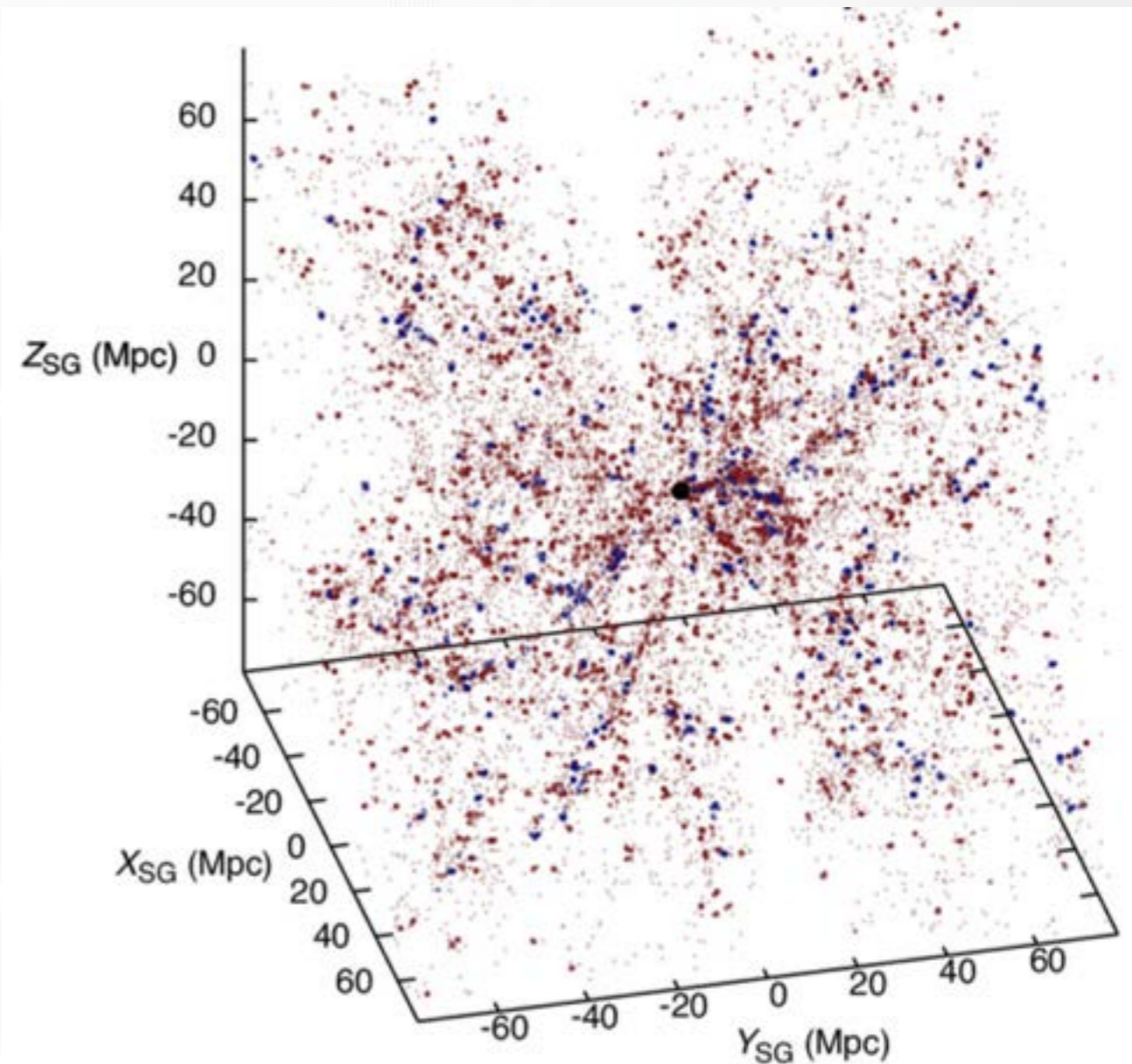
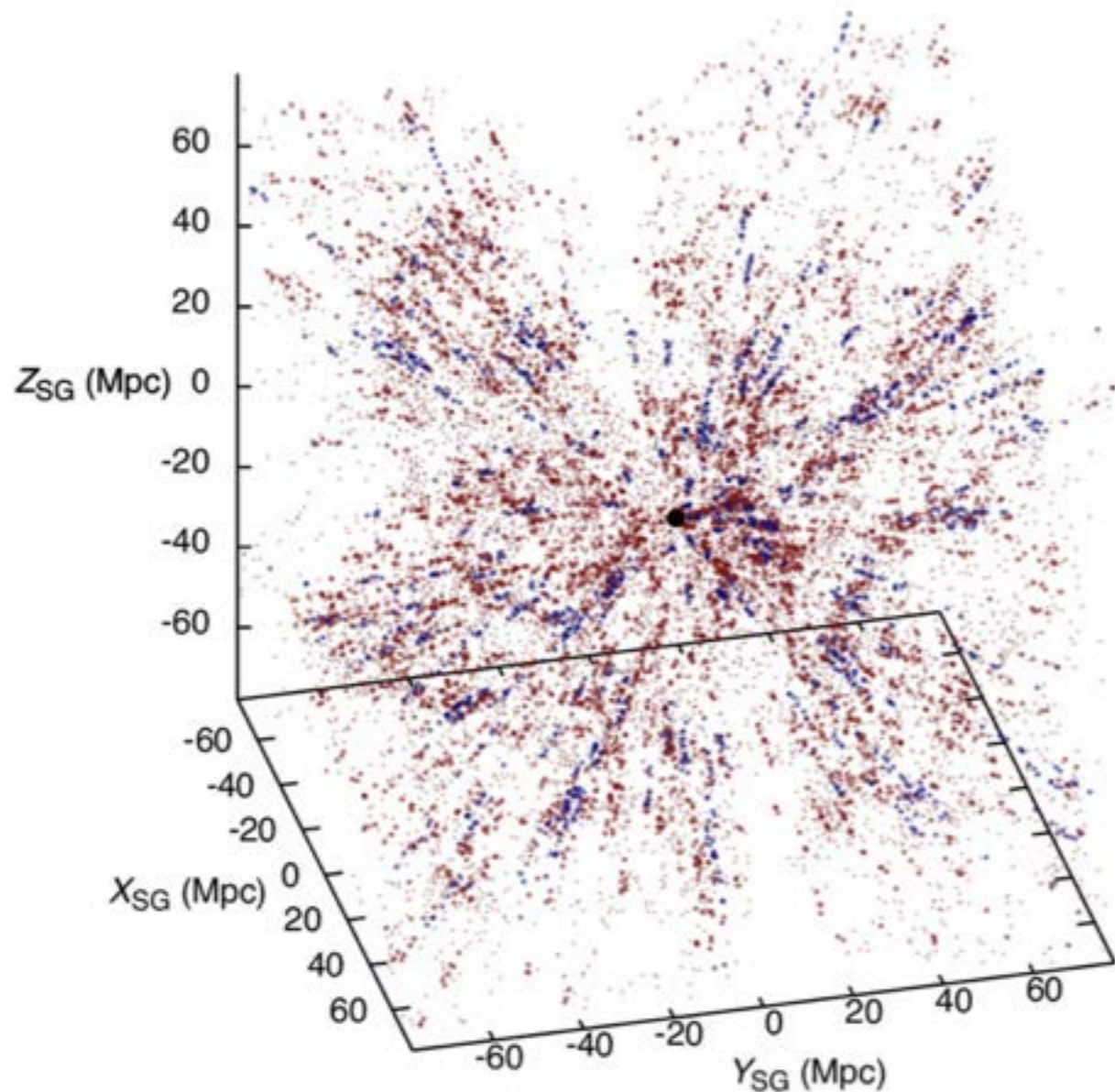
Using friends-of-friends galaxy groups,
we suppress the fingers-of-God distortions.



Friends-of-Friends + multi-modal analysis



Local Universe (2MRS data)



Friends-of-friends galaxy group finder with membership refinement

2016, A&A, 588, A14

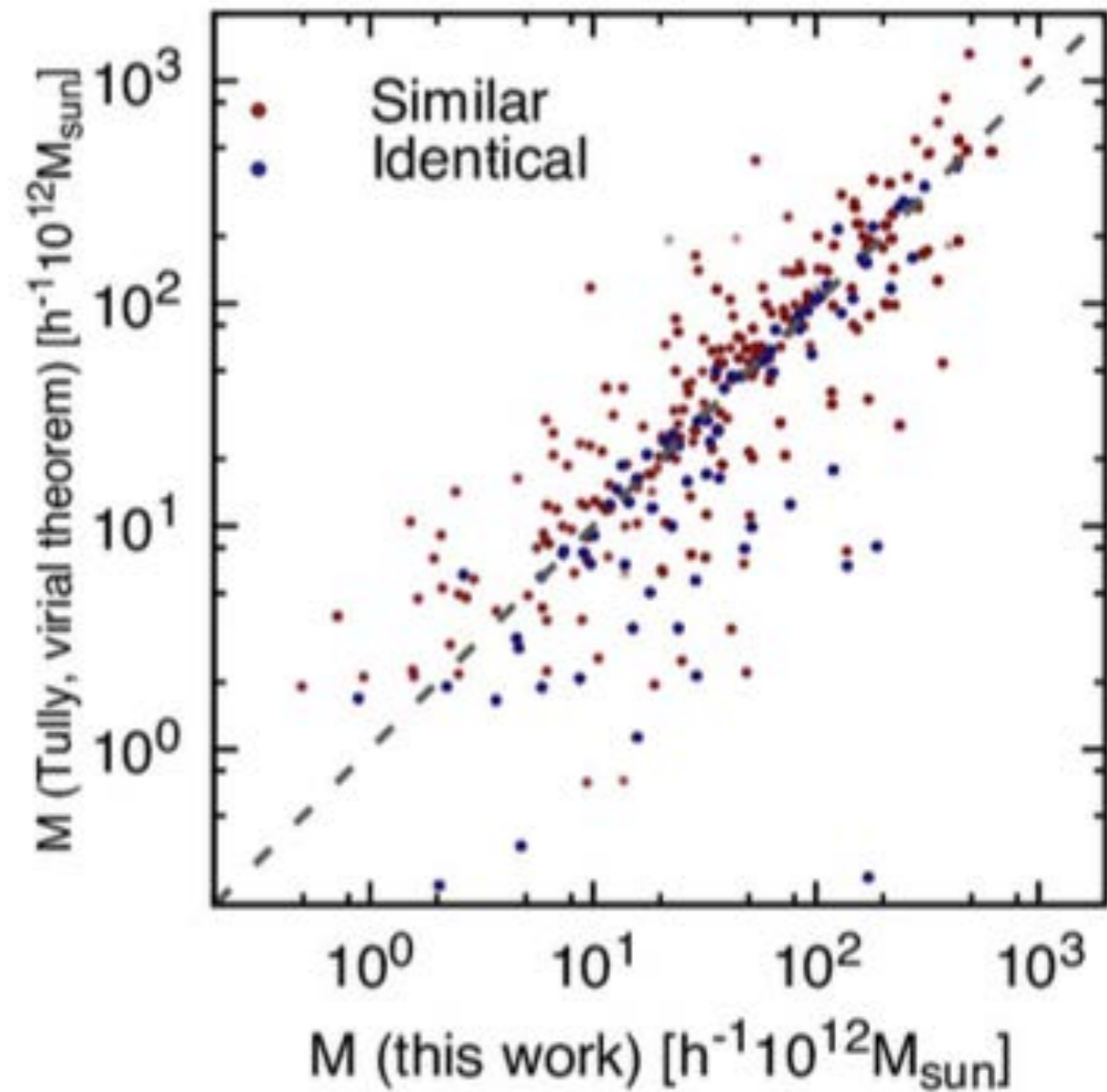
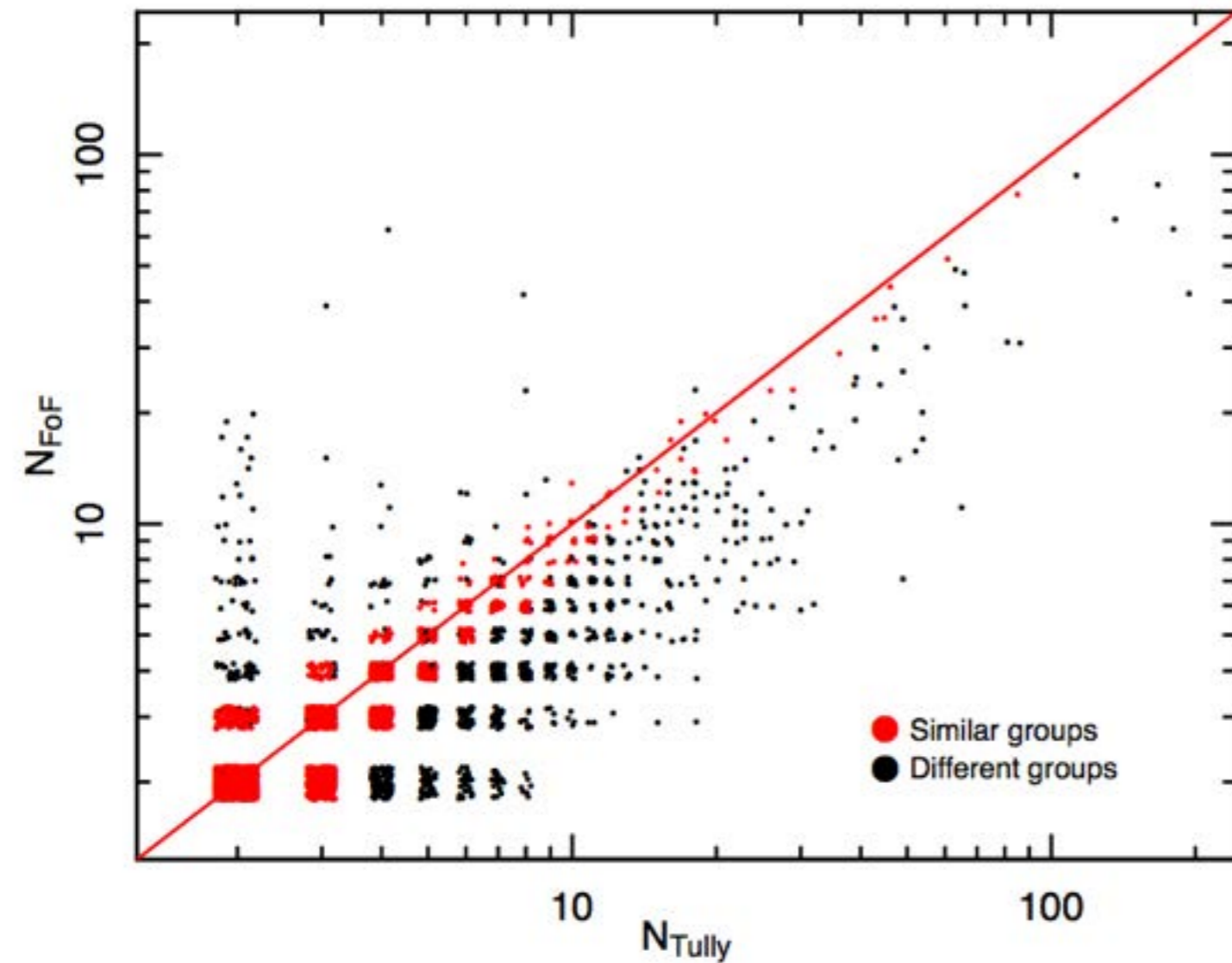
Application to the local Universe[★]

E. Tempel¹, R. Kipper^{1,2}, A. Tamm¹, M. Gramann¹, M. Einasto¹, T. Sepp^{1,2}, and T. Tuvikene¹

FoF groups vs Tully groups

Tempel et al. 2016, A&A, 588, A14

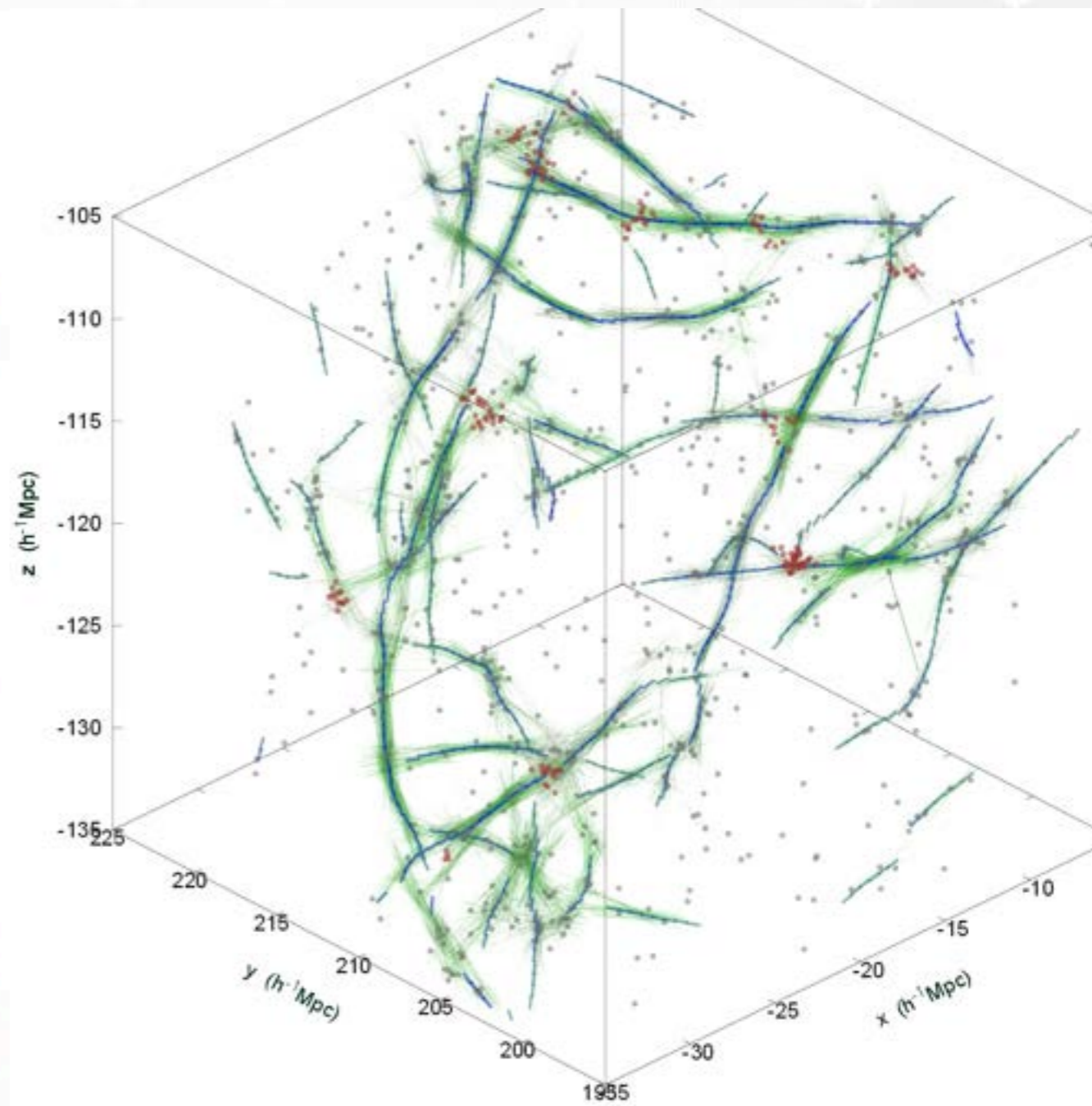
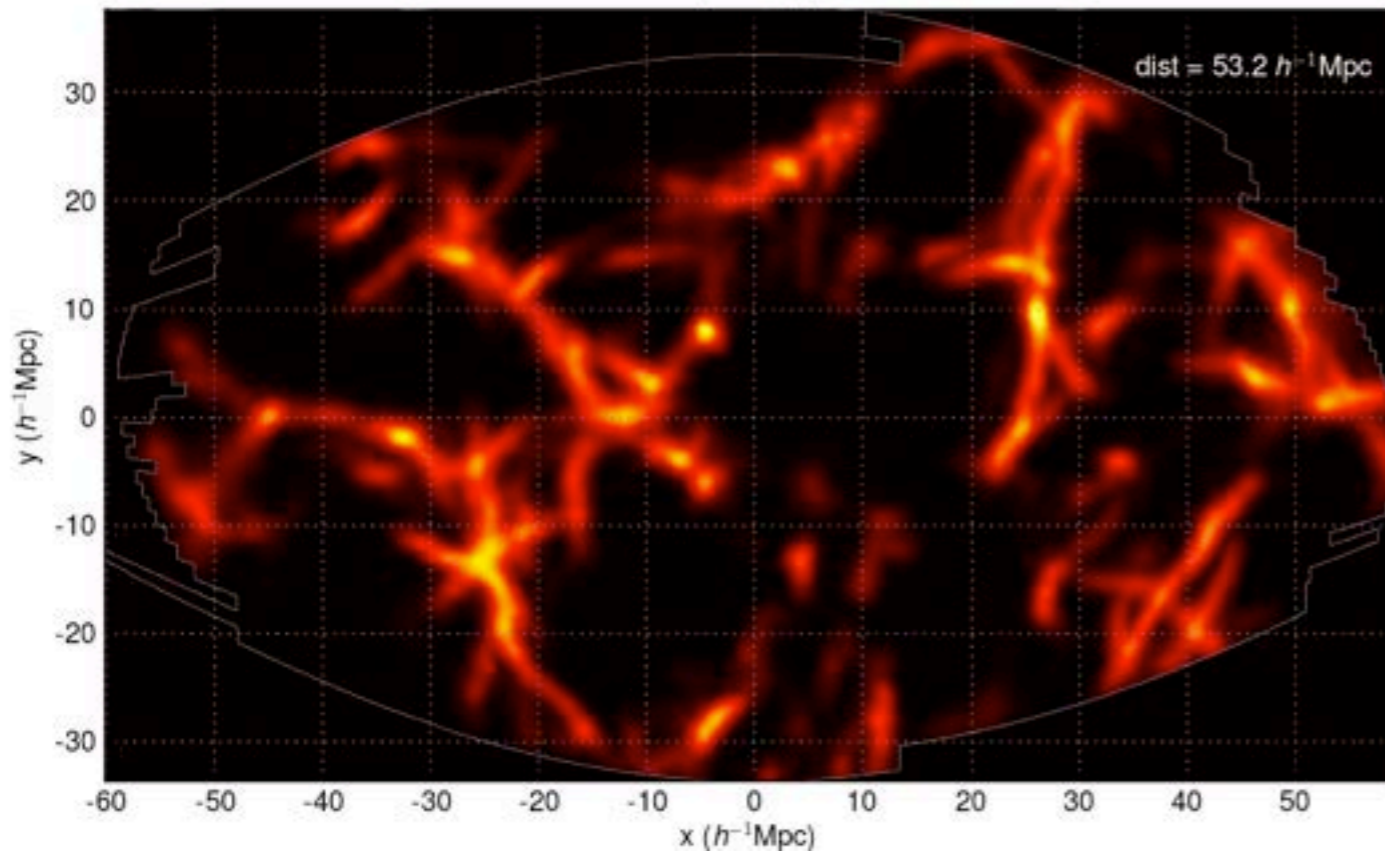
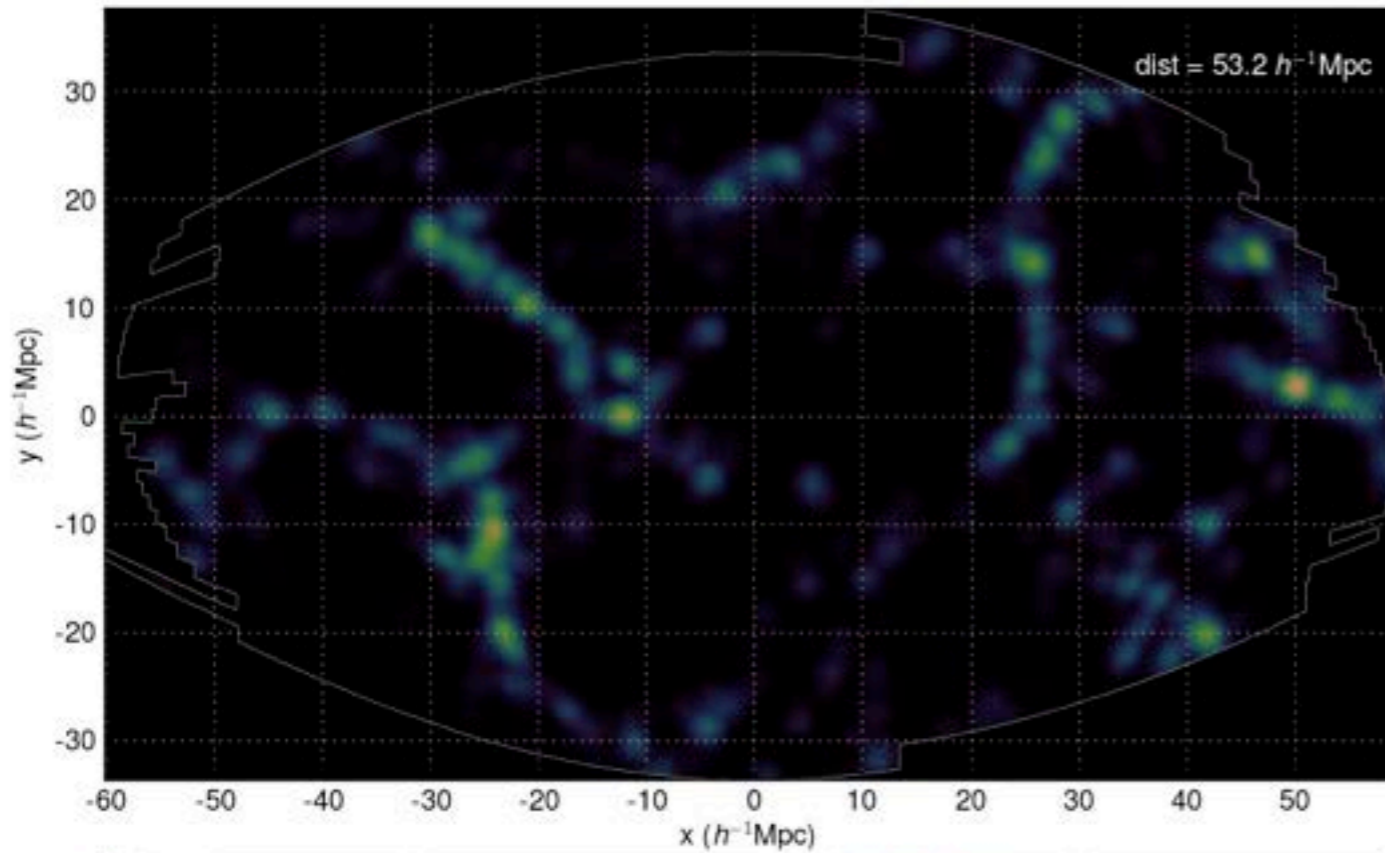
Tully R. Brent, 2015, ApJ, 149, 171





Bisous model — detecting filamentary patterns in point processes

Detected filamentary pattern



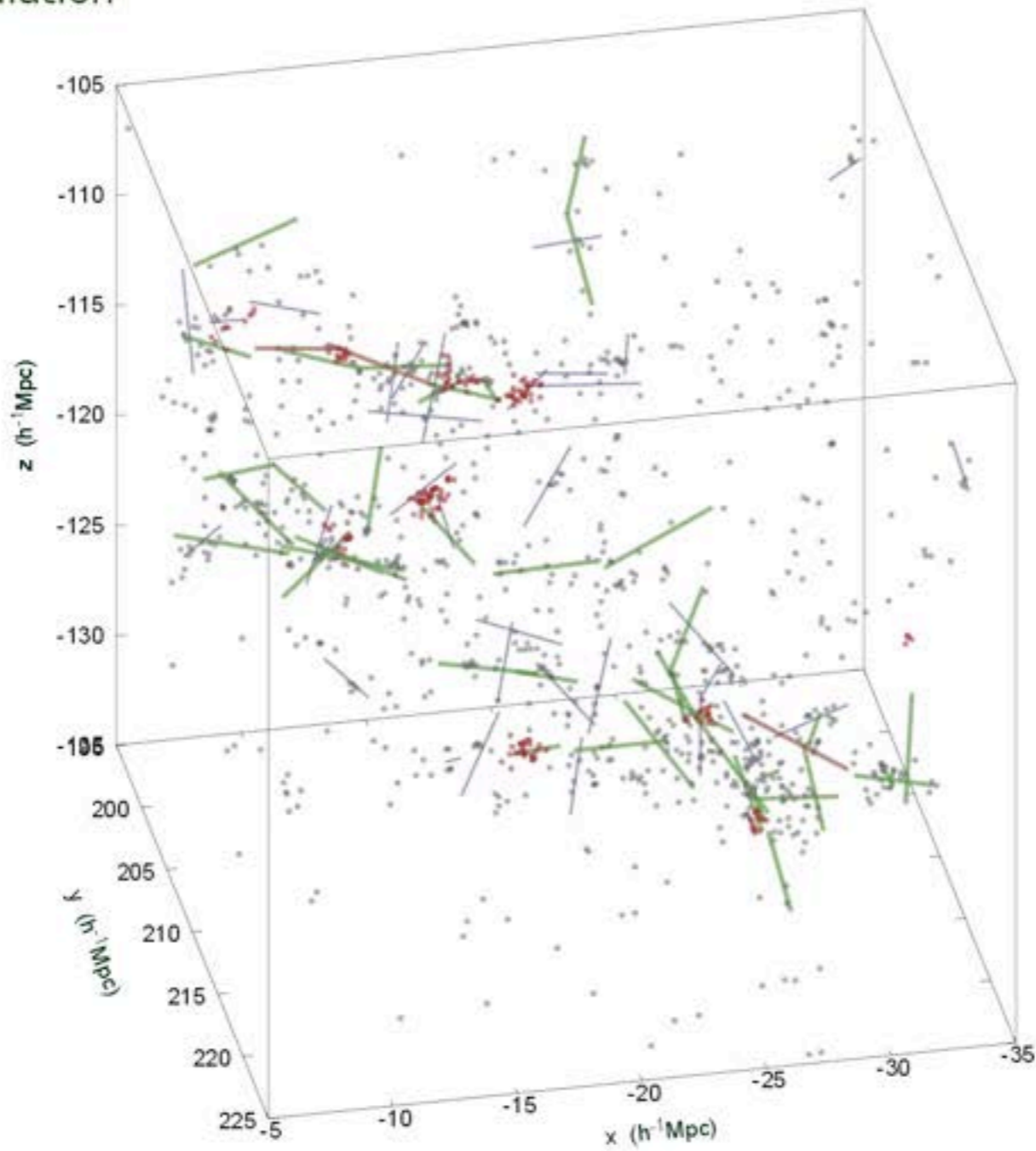
Tempel et al. (2014)

Courtesy: Juhan Liivamägi

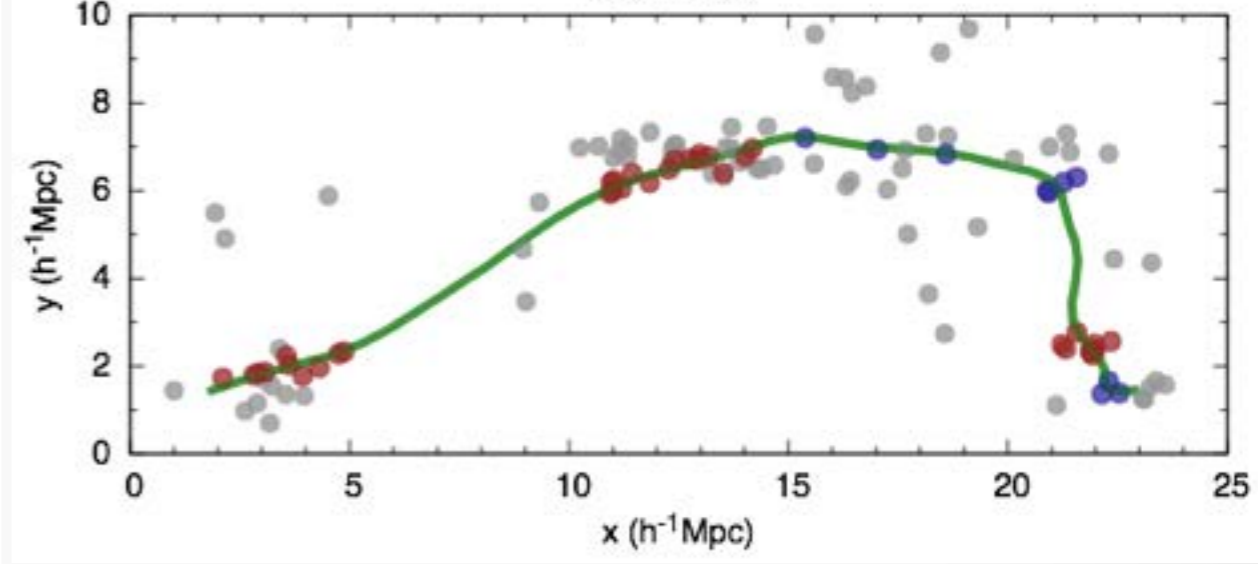
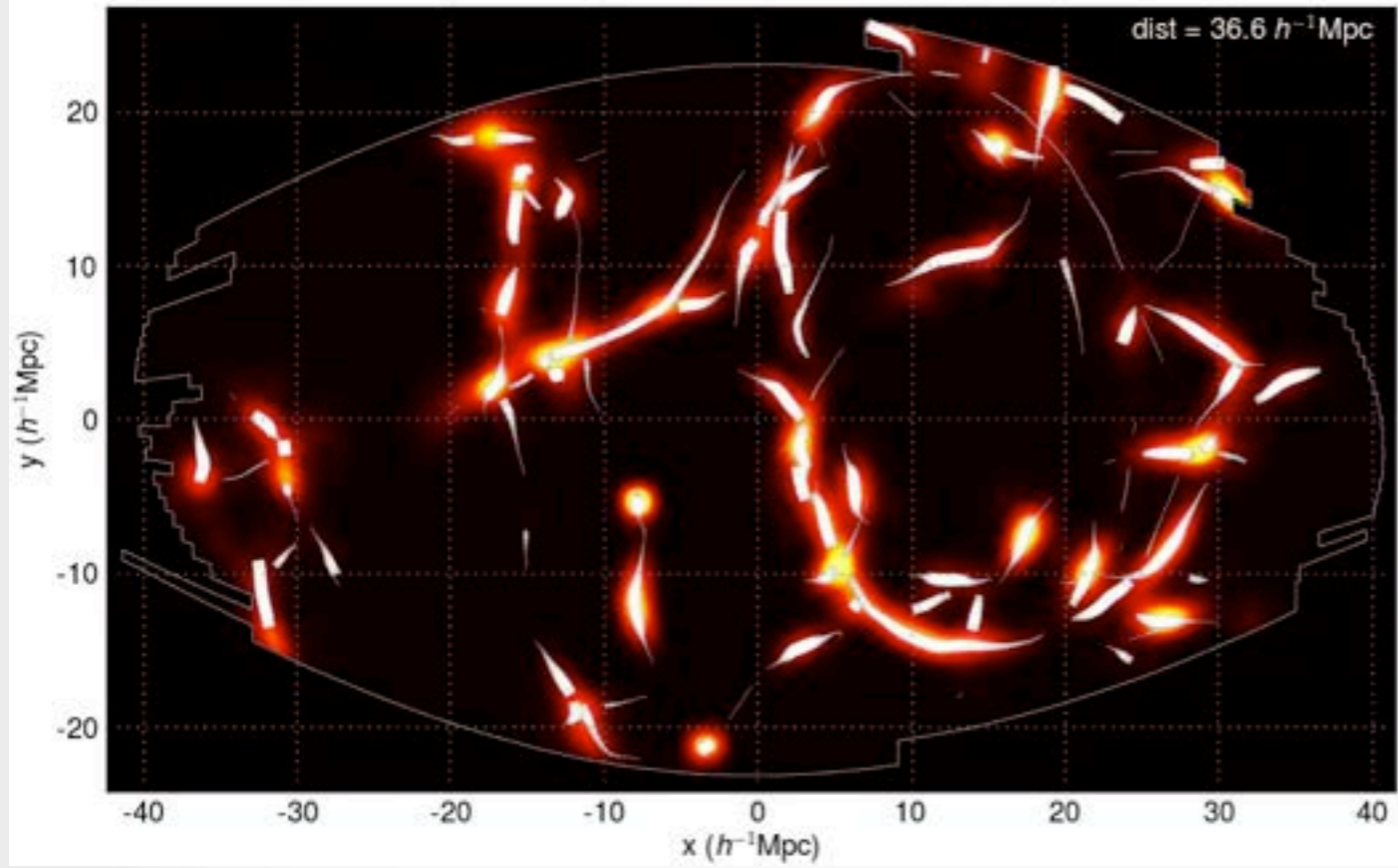
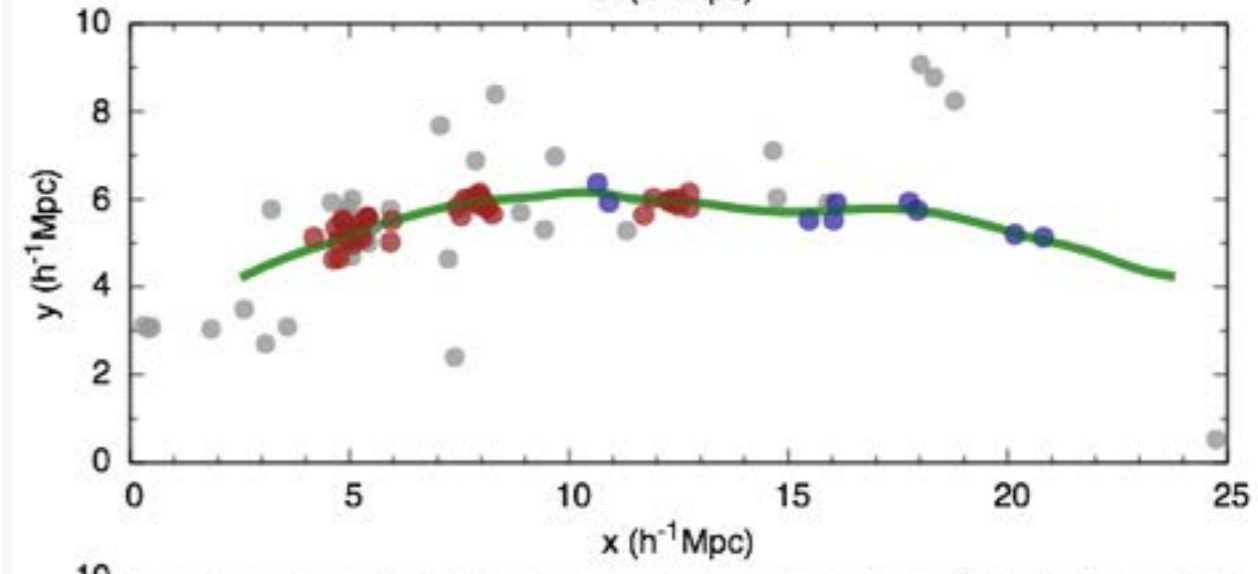
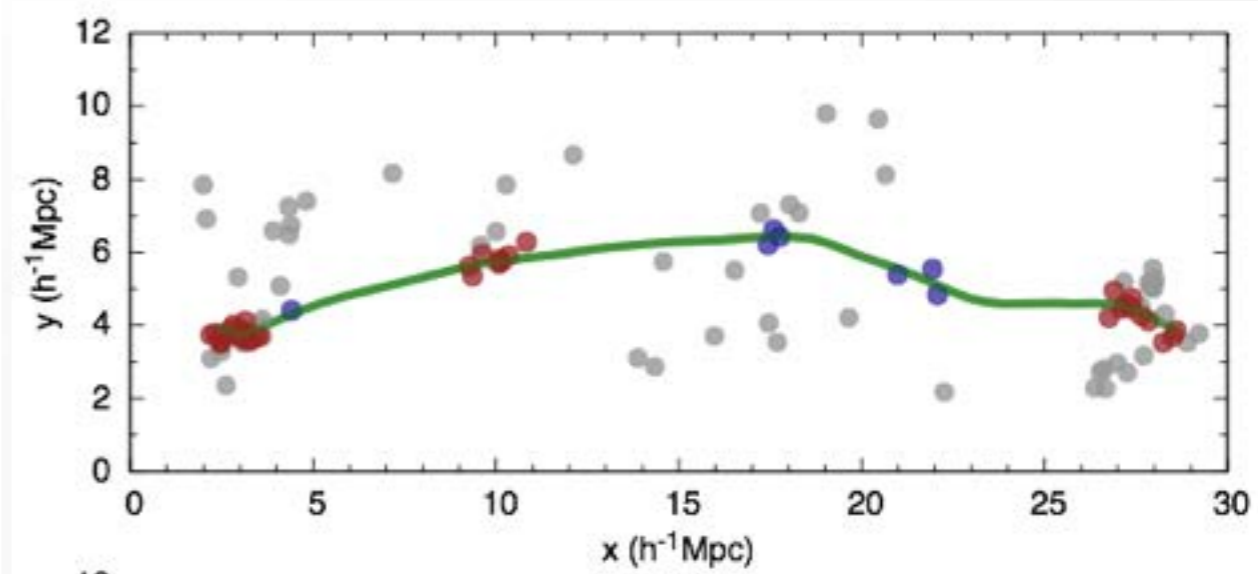
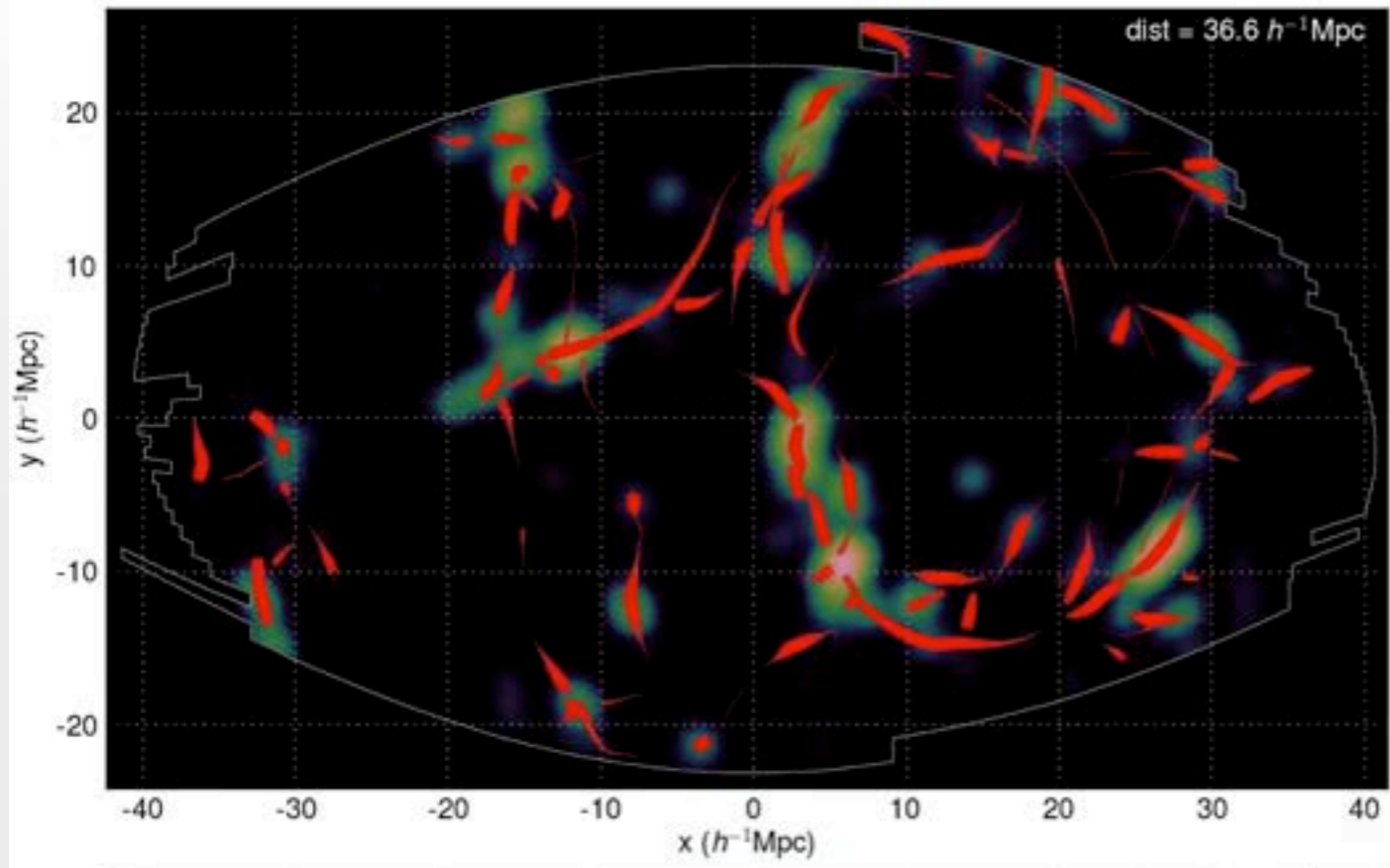
Bisous model in action

Single MCMC simulation

- 0-connected cylinders
- 1-connected cylinders
- 2-connected cylinders
- Galaxies
- Galaxies in groups



Detected filament spines

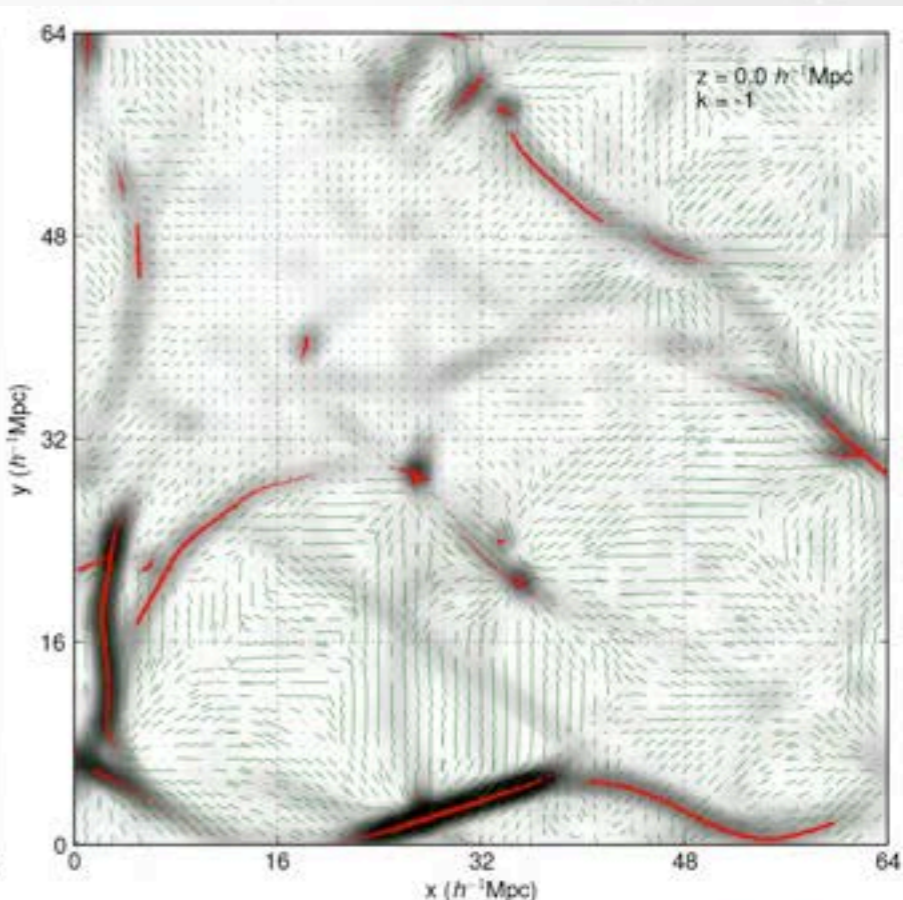
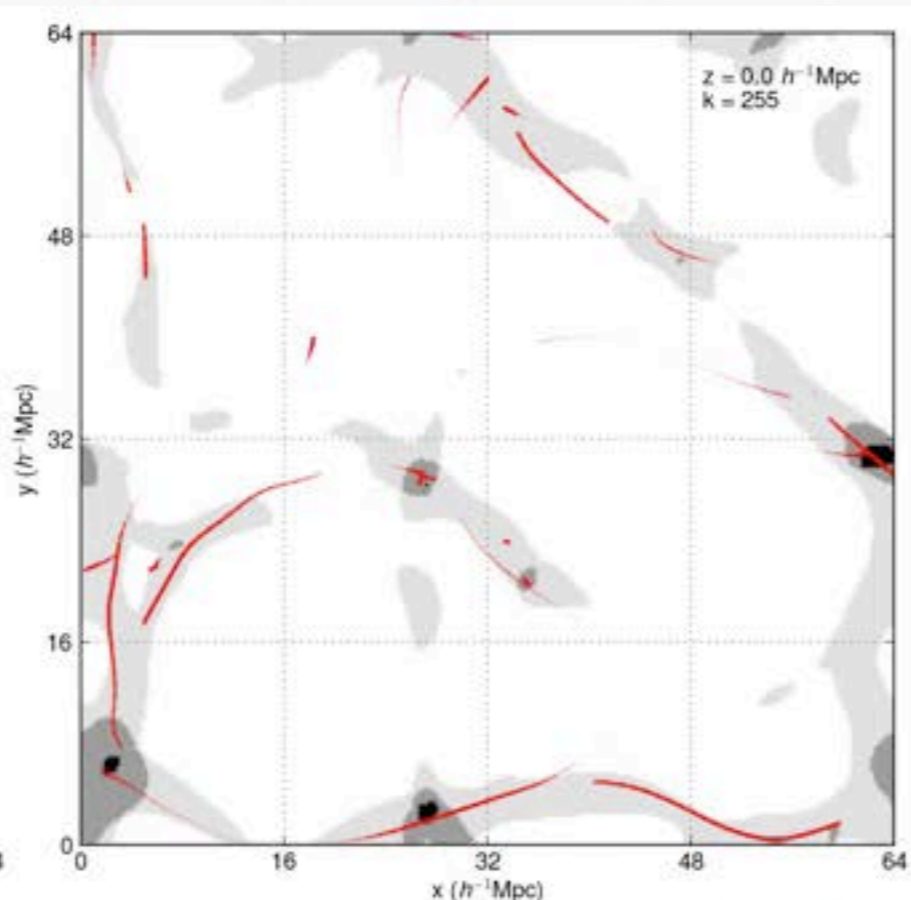
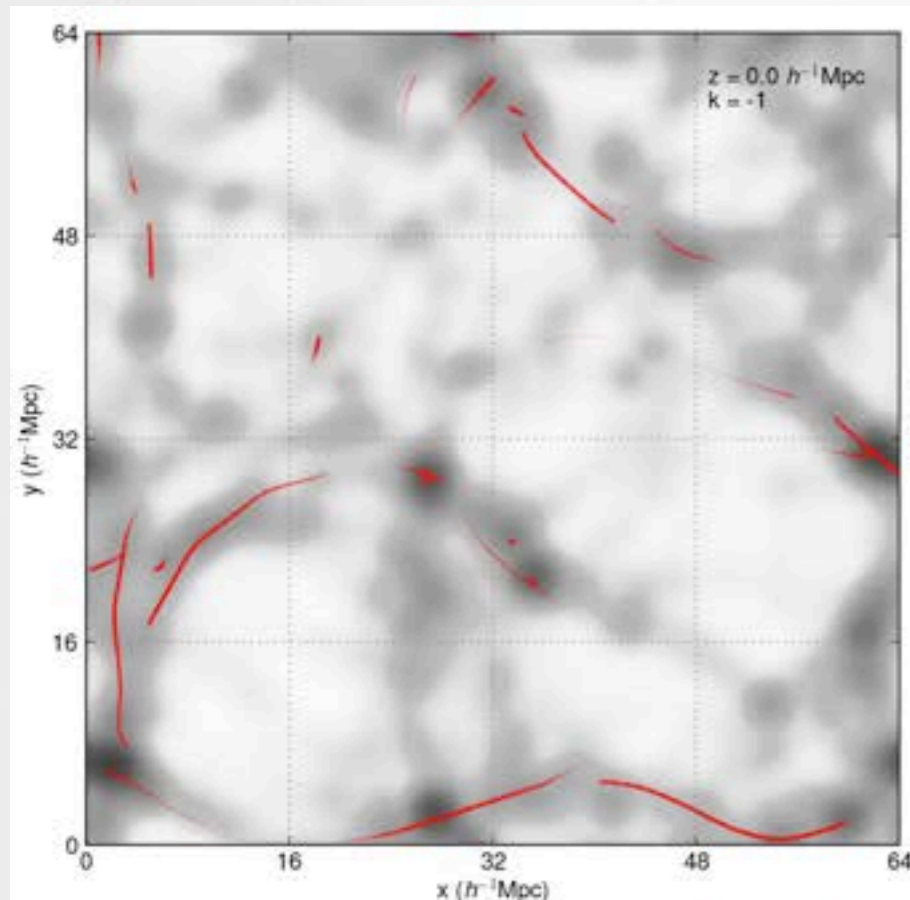
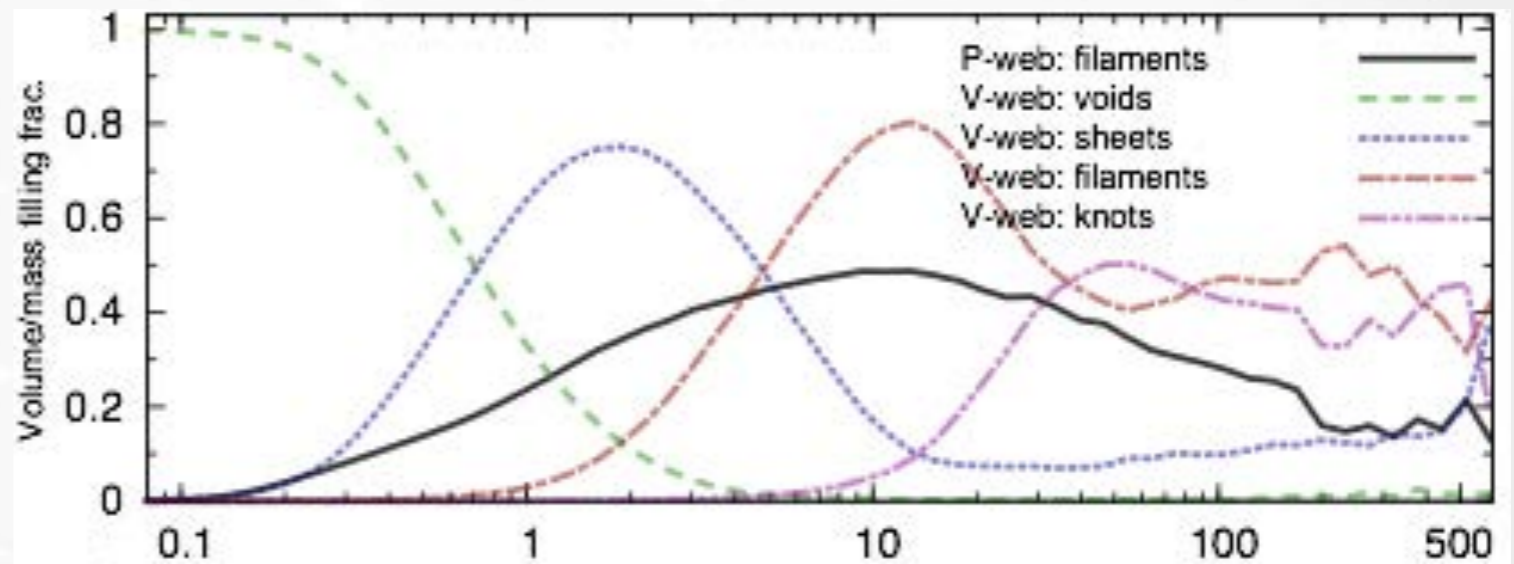
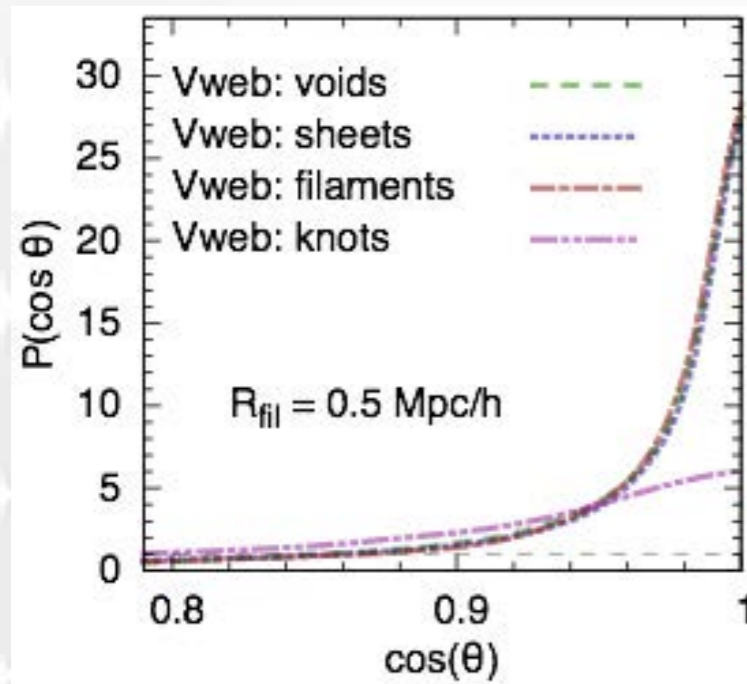


Bisous model - publications:

- ✦ 2013, “Evidence for spin alignment of spiral and elliptical/S0 galaxies in filaments”, (Tempel E., Stoica R. S., Saar E.; MNRAS, 428, 1827)
- ✦ 2013, “Galaxy Spin Alignment in Filaments and Sheets: Observational Evidence” (Tempel E., Libeskind N. I.; ApJL, 775, 42)
- ✦ 2014, “Orientation of cosmic web filaments with respect to the underlying velocity field” (Tempel E., Libeskind N. I., Hoffman Y., Liivamägi L. J., Tamm A.; MNRAS, 437, L11)
- ✦ 2014, “Detecting filamentary pattern in the cosmic web: a catalogue of filaments for the SDSS” (Tempel E., Stoica R. S., Martínez V. J., Liivamägi L. J., Castellan G., Saar E.; MNRAS, 438, 3465)
- ✦ 2014, “Galaxy filaments as pearl necklaces” (Tempel E., Kipper R., Saar E., Bussov M., Hektor A., Pelt J.; A&A, 572, A8)
- ✦ 2015, “Galaxies in Filaments have More Satellites: The Influence of the Cosmic Web on the Satellite Luminosity Function in the SDSS” (Guo Q., Tempel E., Libeskind N. I.; ApJ, 800, 112)
- ✦ 2015, “Galaxy pairs align with Galactic filaments” (Tempel E., Tamm A.; A&A, 576, L5)
- ✦ 2015, “The alignment of satellite galaxies and cosmic filaments: observations and simulations” (Tempel E., Guo Q., Kipper R., Libeskind N. I.; MNRAS, 450, 2727)
- ✦ 2015, “Missing baryons traced by the galaxy luminosity density in the large-scale WHIM filaments” (Nevalainen J., Tempel E., Liivamägi L. J. et al.; A&A, 538, A142)
- ✦ 2015, “Filaments from the galaxy distribution and from the velocity field in the local universe” (Libeskind N. I., Tempel E., Hoffman Y., Tully R. B., Courtois H.; MNRAS, 453, L108)
- ✦ 2016, “A possible Chandra and Hubble Space Telescope detection of extragalactic WHIM towards PG 1116+215” (Bonamente M., Nevalainen J., Tilton E., Liivamägi J., Tempel E., Heinämäki P., Fang T.; MNRAS, 457, 4236)
- ✦ 2016, “The alignment of galaxy spin with the shear field in observations” (Pahwa I., Libeskind N. I., Tempel E. et al.; MNRAS, 457, 695)
- ✦ 2016, “Bisous model - Detecting filamentary patterns in point processes” (Tempel E., Stoica R. S., Kipper R., Saar E.; A&C, 16, 17)

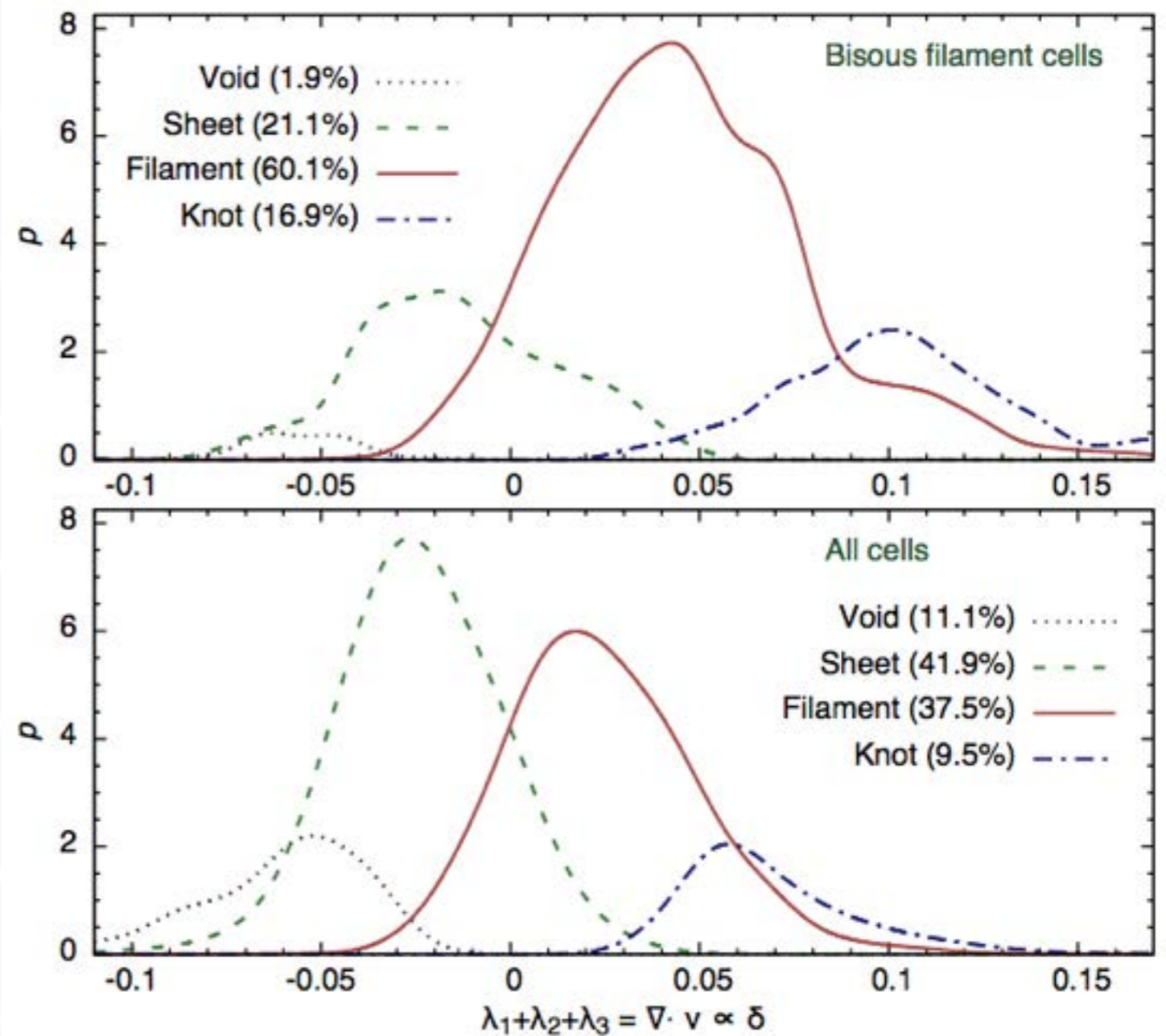
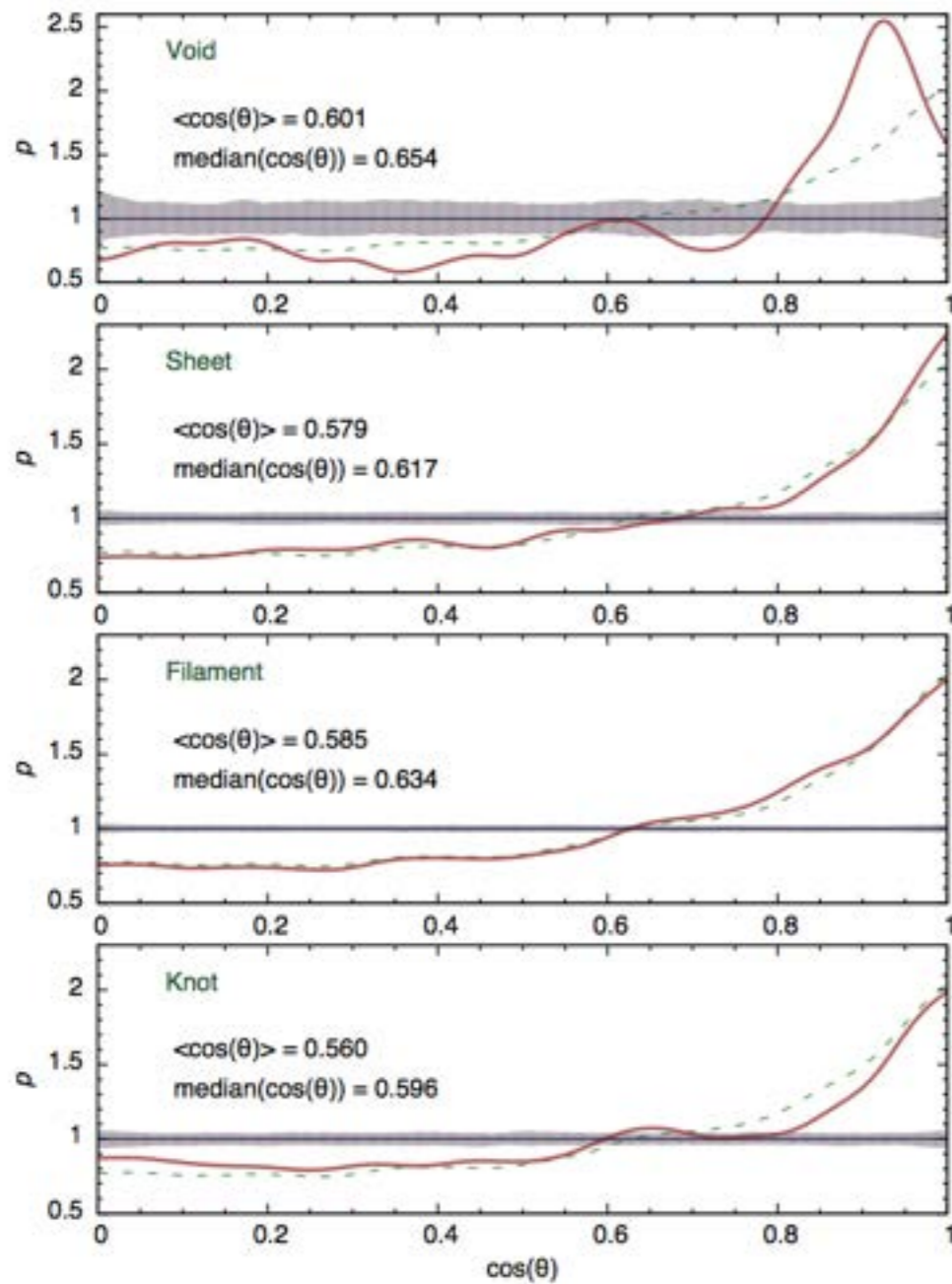
Orientation of cosmic web filaments with respect to the underlying velocity field

Tempel, Libeskind, Hoffmann et al. (2014)



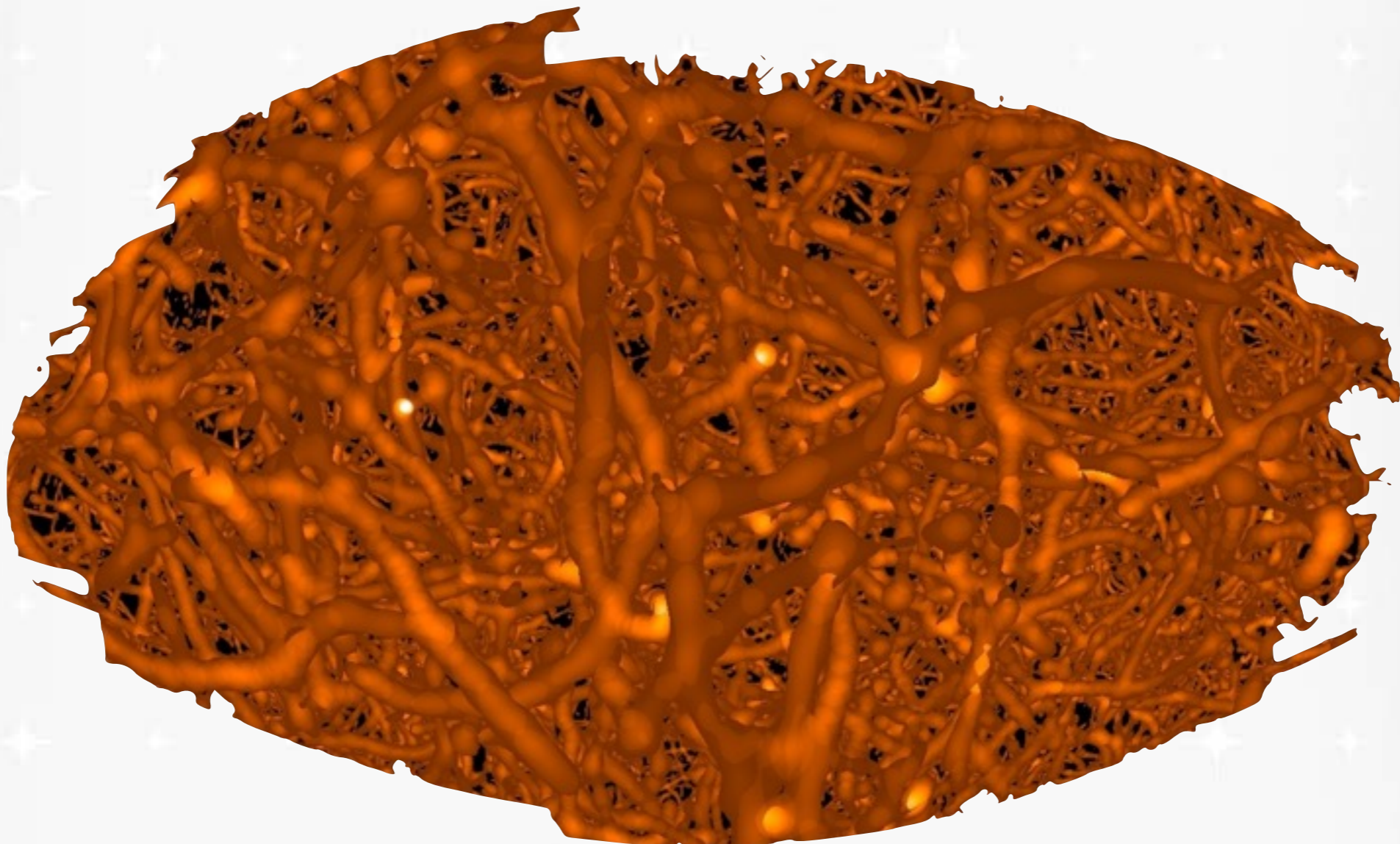
Filaments from the galaxy distribution and from the velocity field in the local universe

Libeskind, Tempel, Hoffman, Tully, Courtois (2015)

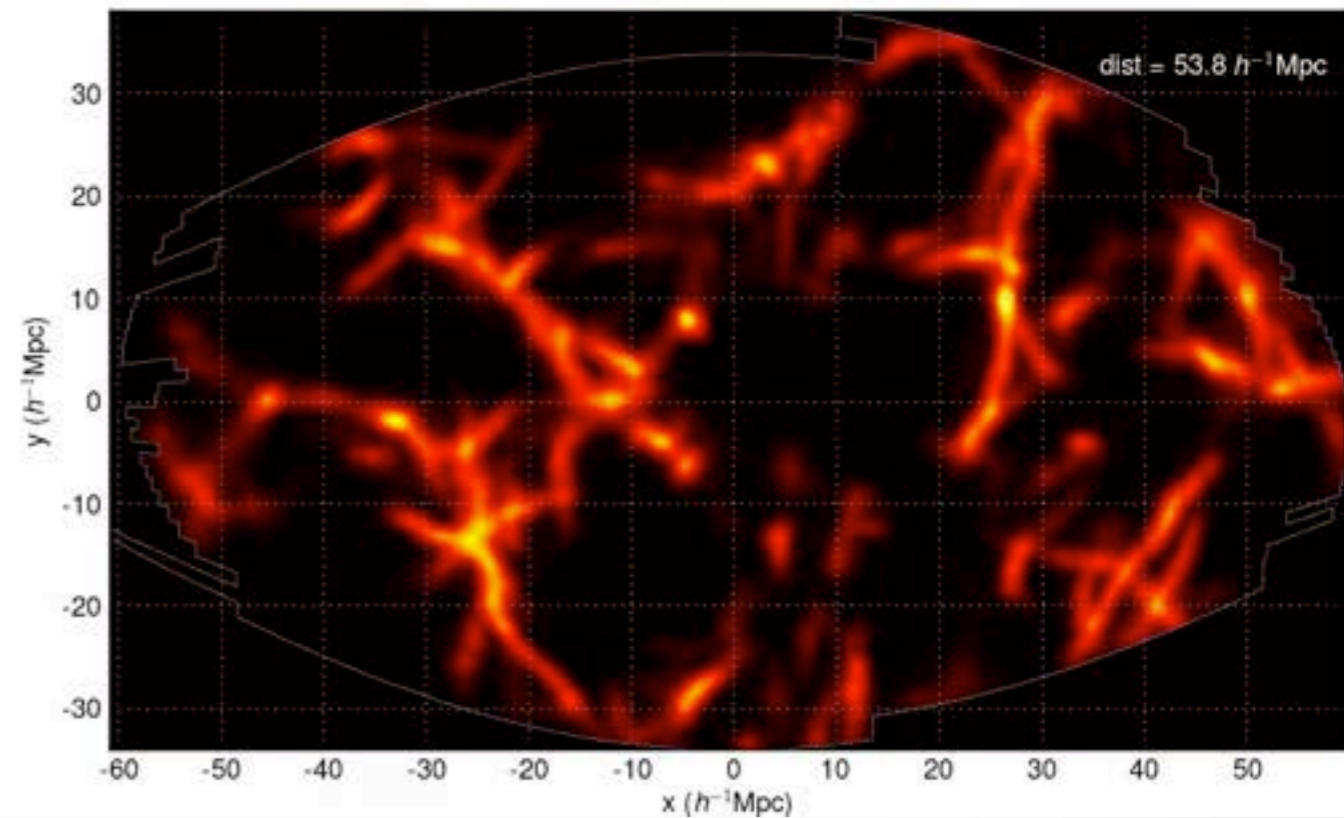
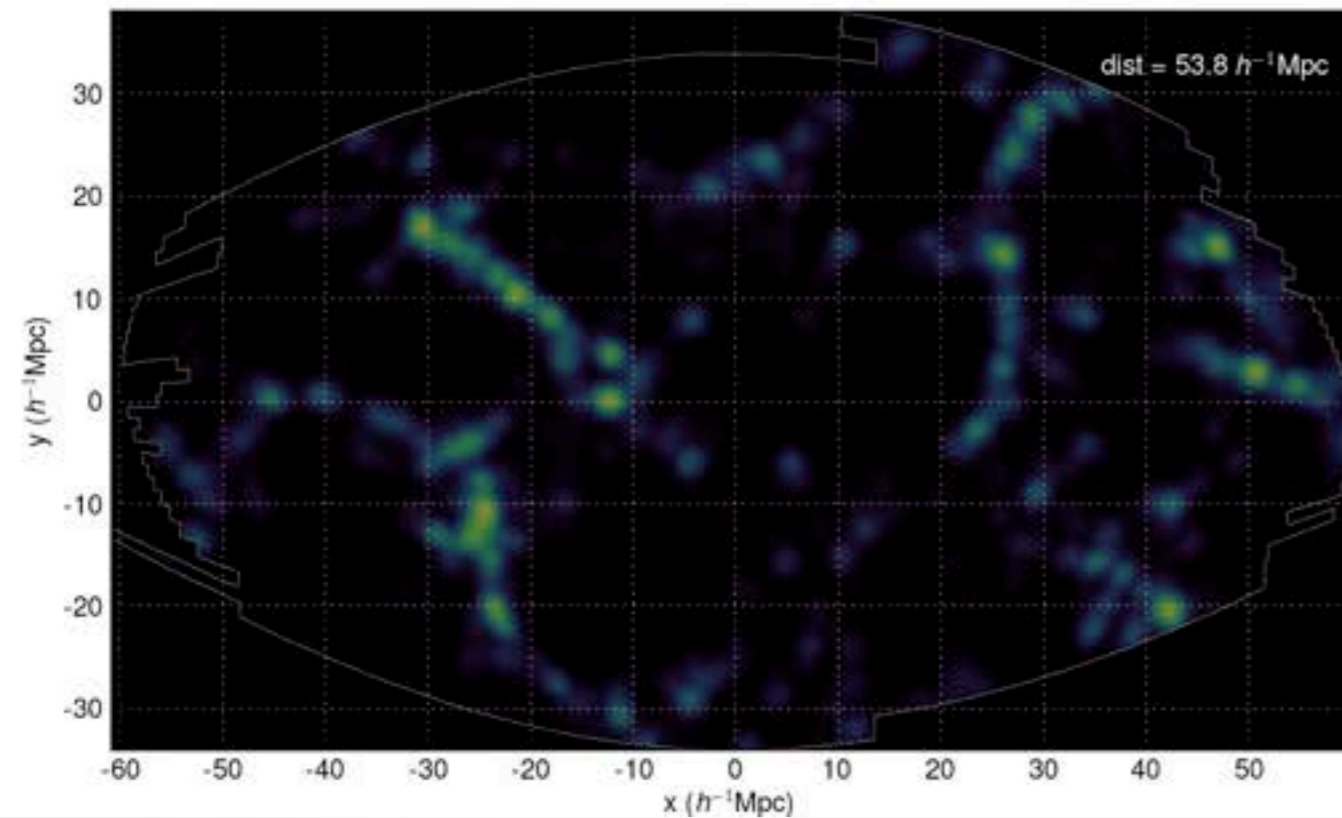




Filaments in the SDSS



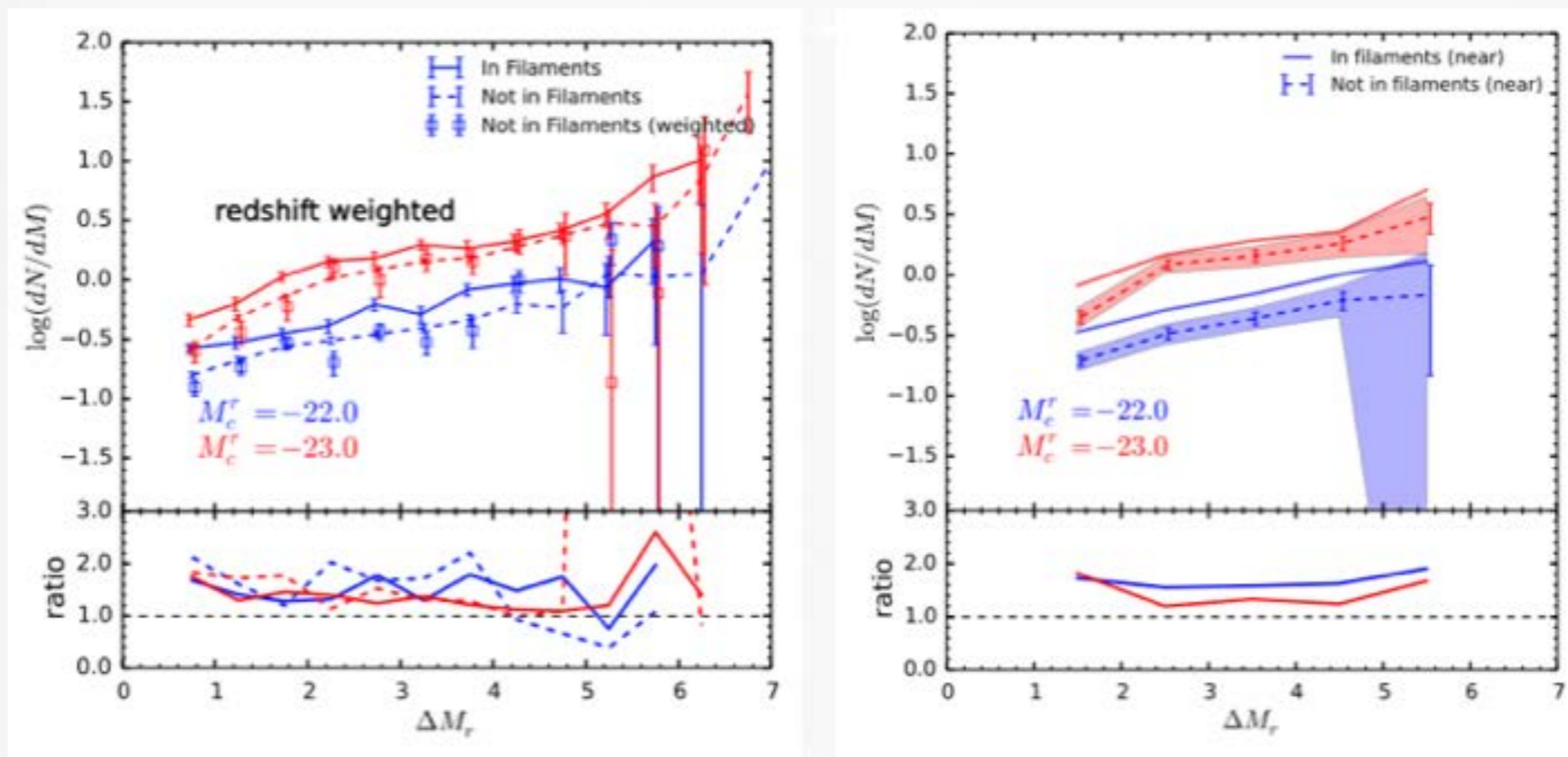
The alignment of galaxies in filaments



Galaxies in filaments have more satellites: the influence of the cosmic web on the satellite luminosity function in the SDSS

Guo, Tempel & Libeskind (2015)

Number of satellites

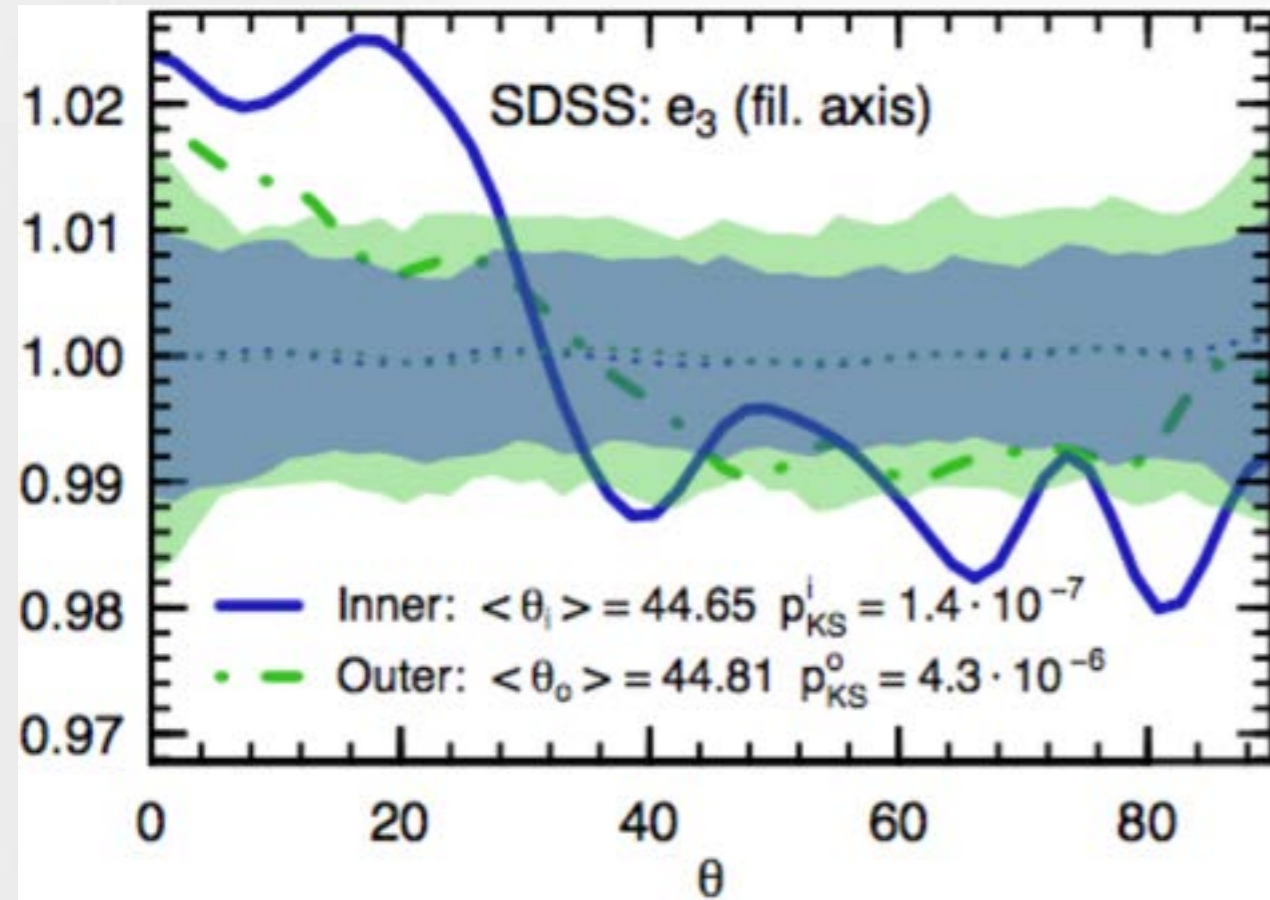


Satellite luminosity with respect to central galaxy

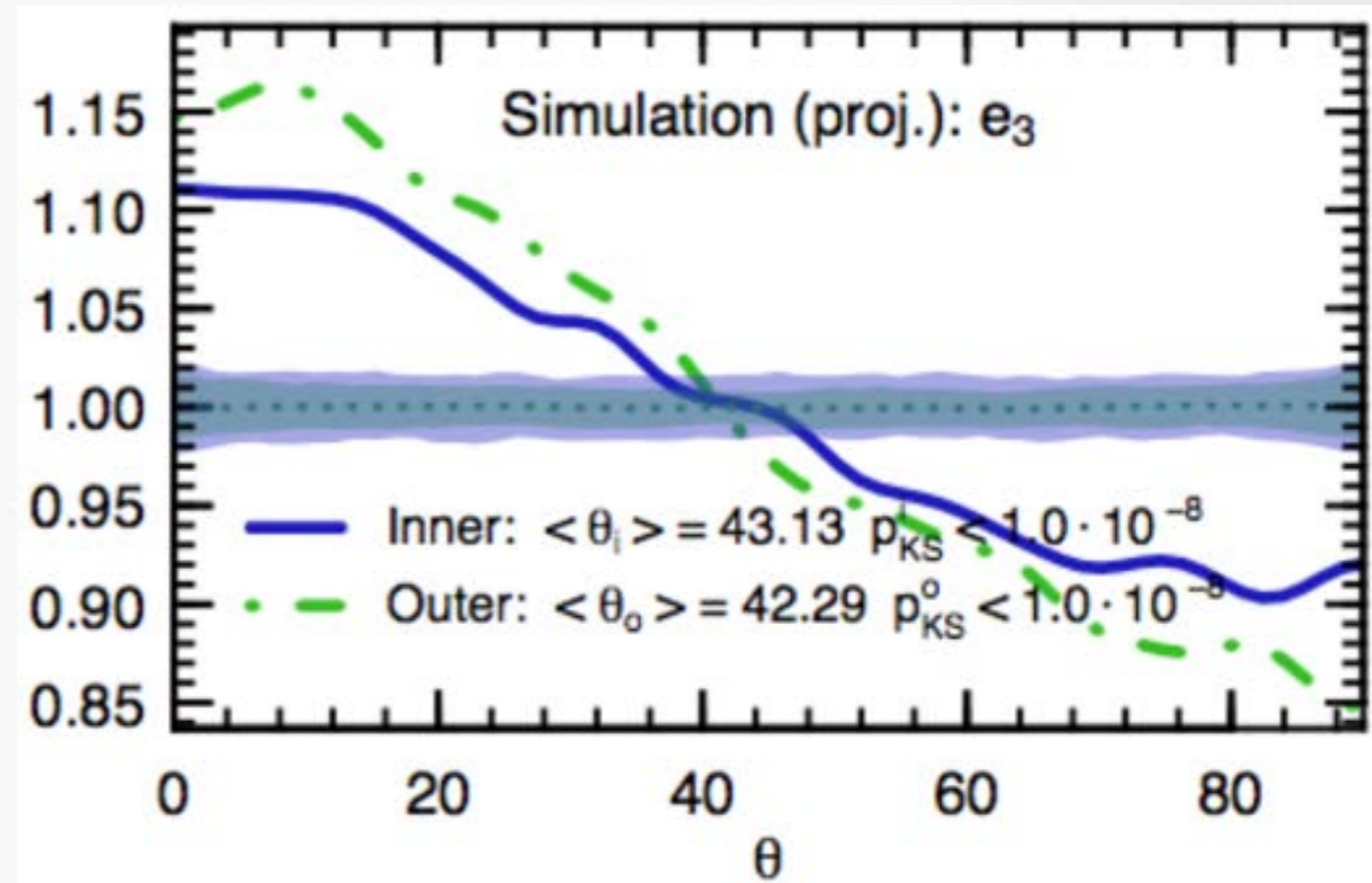
The alignment of satellite galaxies and cosmic filaments: observations and simulations

Tempel, Guo, Kipper, Libeskind (2015)

SDSS observations



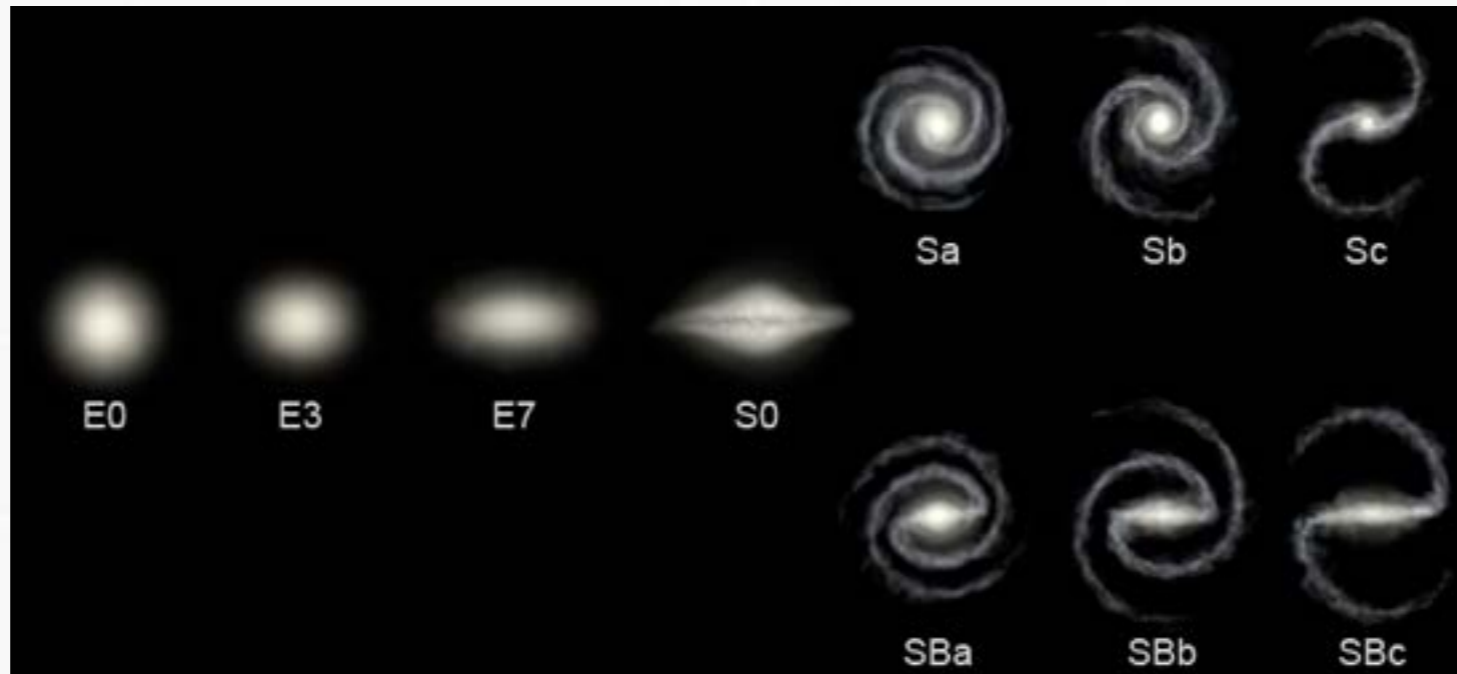
Millennium simulation



Angle between the satellite position and filament axis

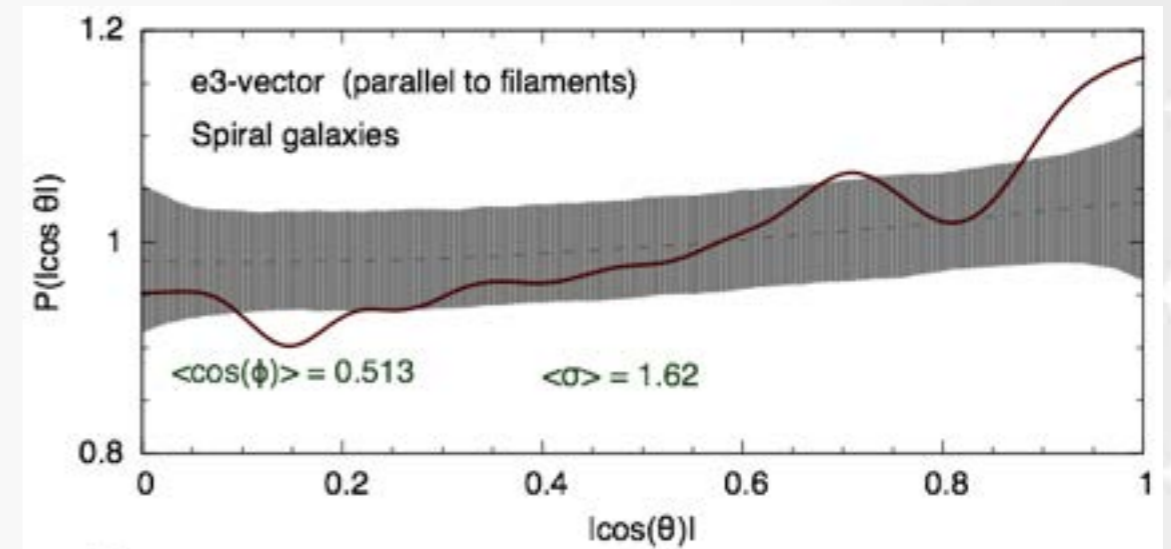
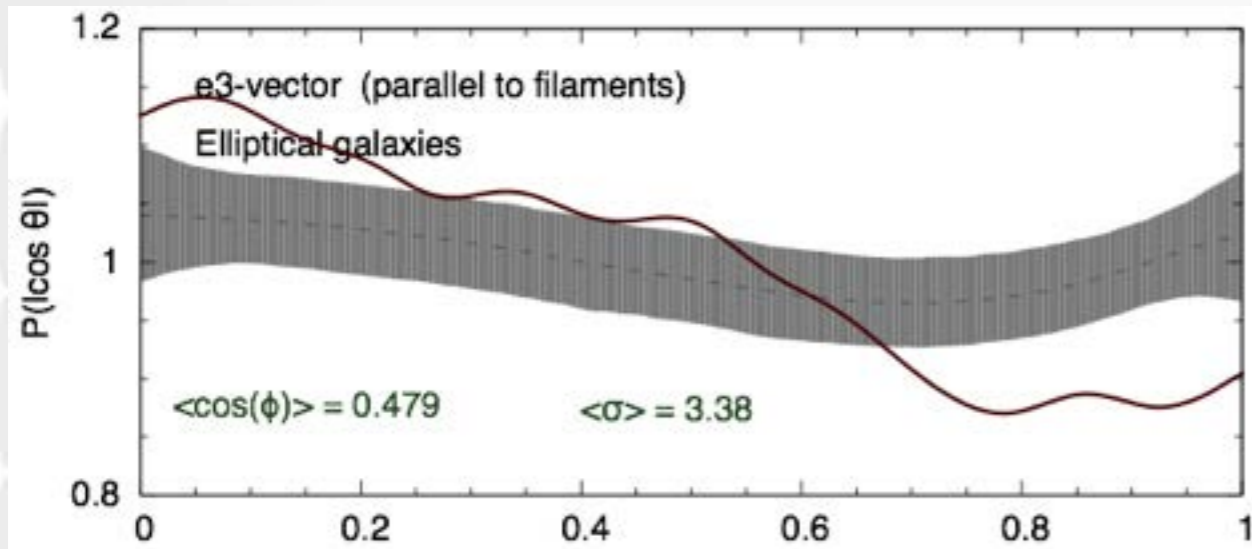
Galaxy Spin Alignment in Filaments: Observational Evidence

Tempel & Libeskind (2013); Tempel, Stoica & Saar (2013)



Elliptical galaxies

Spiral galaxies



Galaxy pairs align with galactic filaments

Tempel & Tamm (2015)

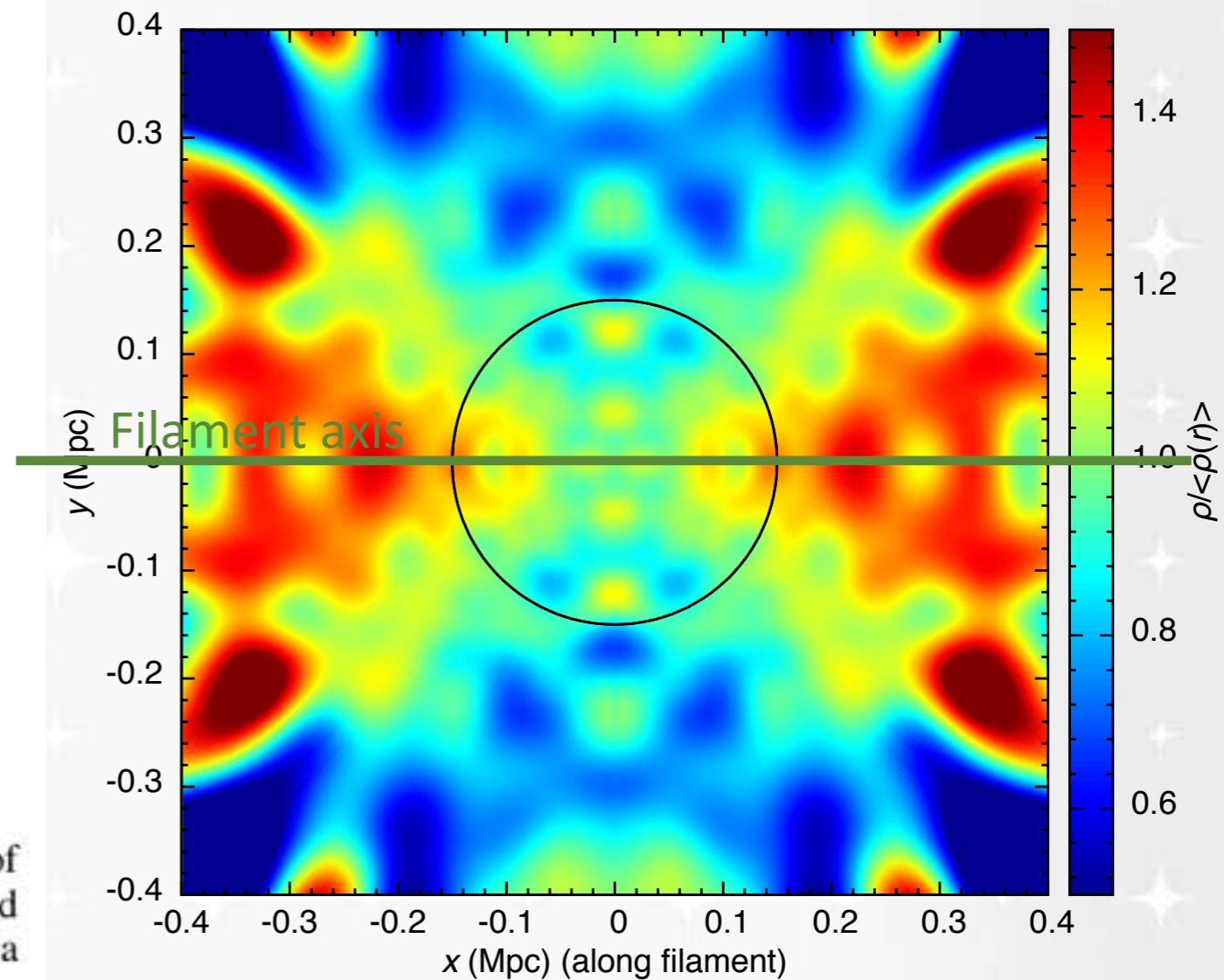
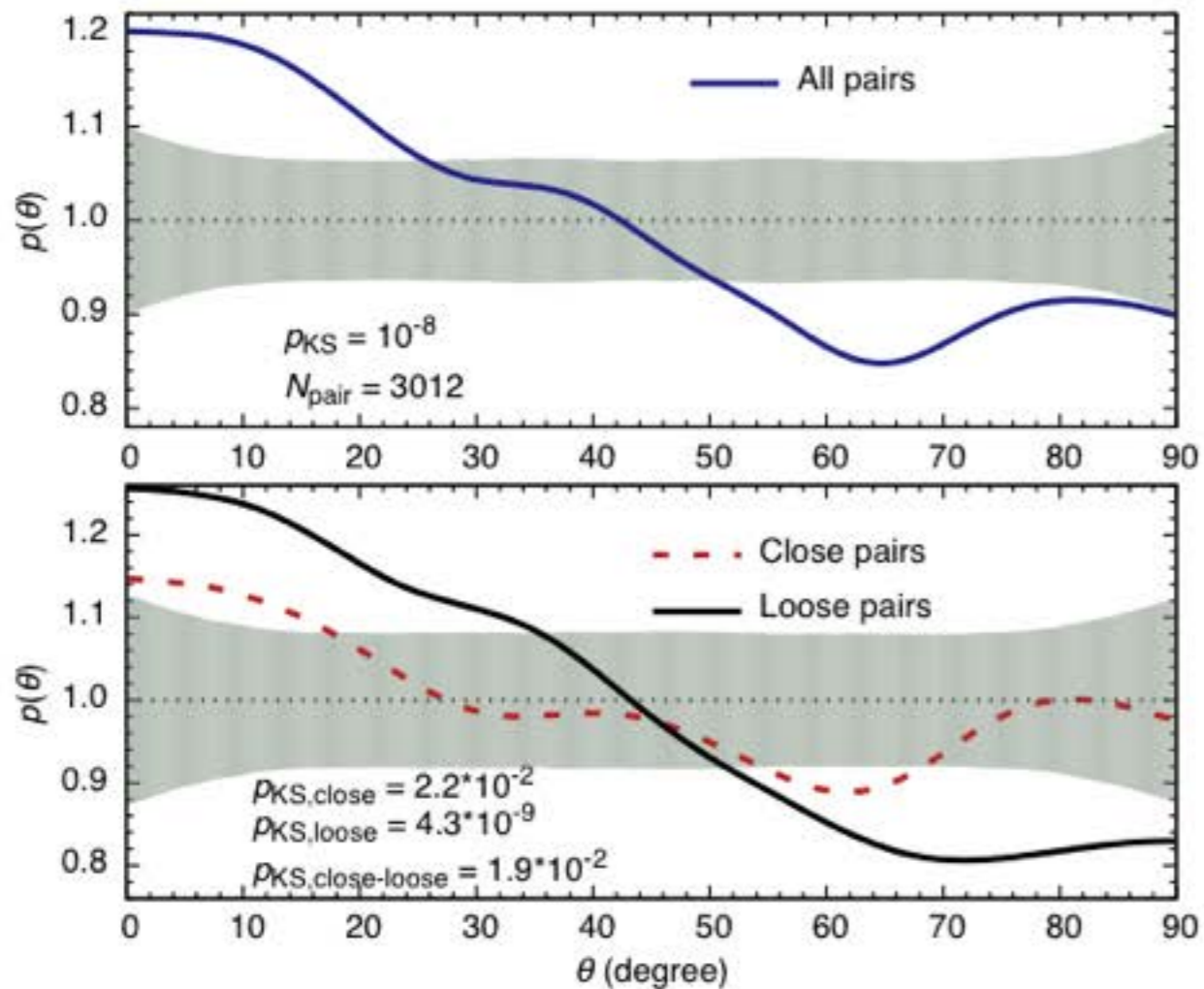
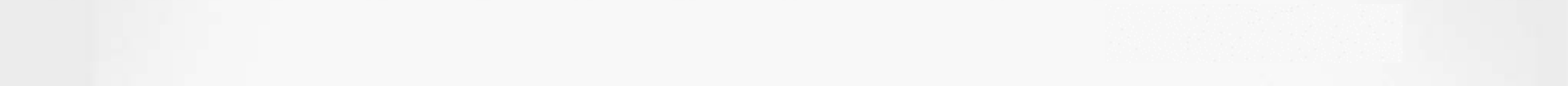


Fig. 2. *Upper panel:* probability distribution function (blue solid line) of the projected (in the plane of the sky) angles between galaxy pairs and their host filaments. The KS-test value that the sample is drawn from a uniform distribution is 10^{-8} . The filled area shows the 95% confidence region for a randomised distribution of 3012 pairs. *Lower panel:* the same as in the upper panel for two equal-size subsamples: close pairs ($d_{\text{sep}} < 0.3$ Mpc; red dashed line) and loose pairs ($d_{\text{sep}} > 0.3$ Mpc; black solid line).



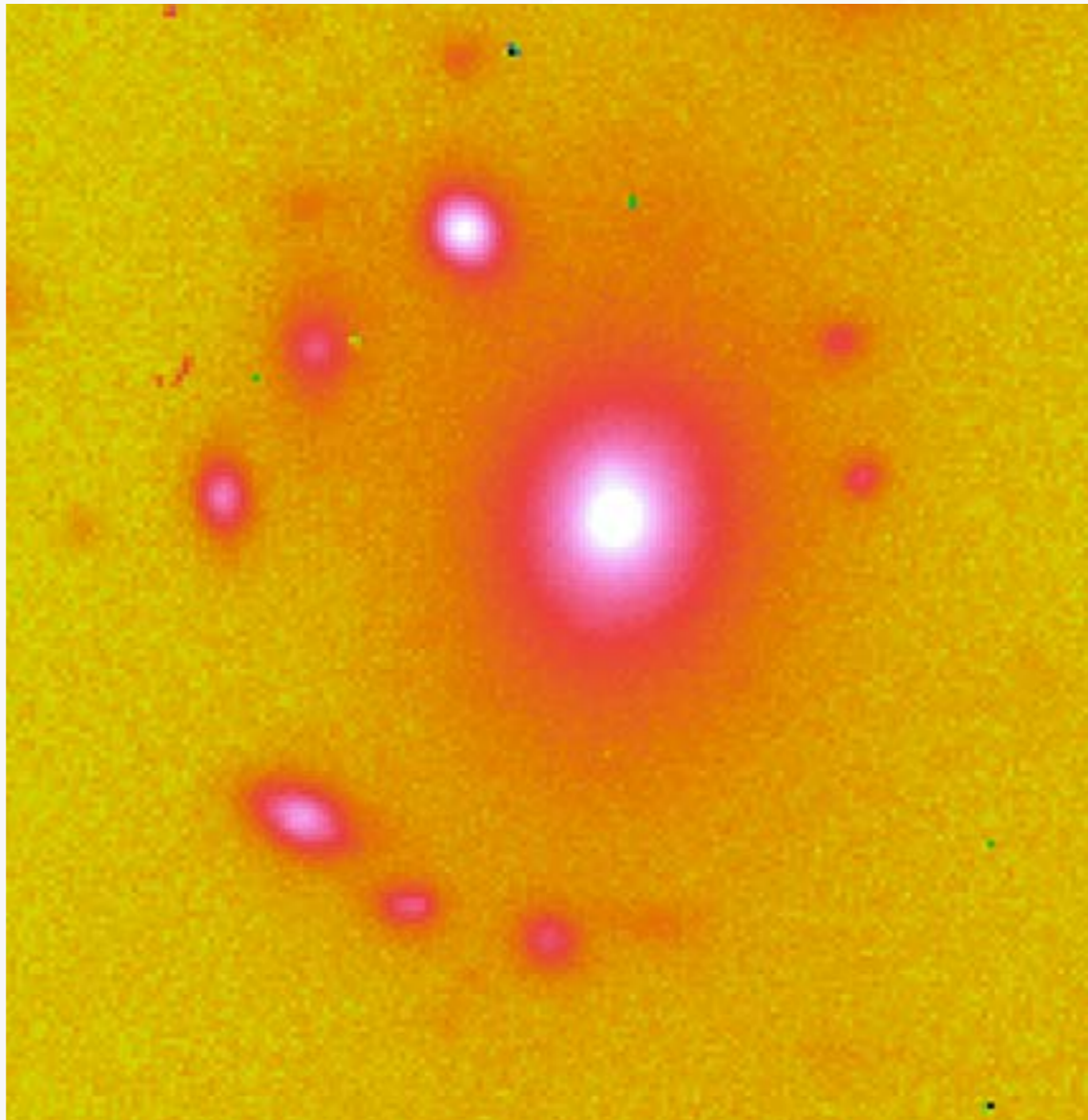
Conclusions

Galaxy filaments have a measurable effect on the evolution of galaxies





Mysterious object



Thank you!