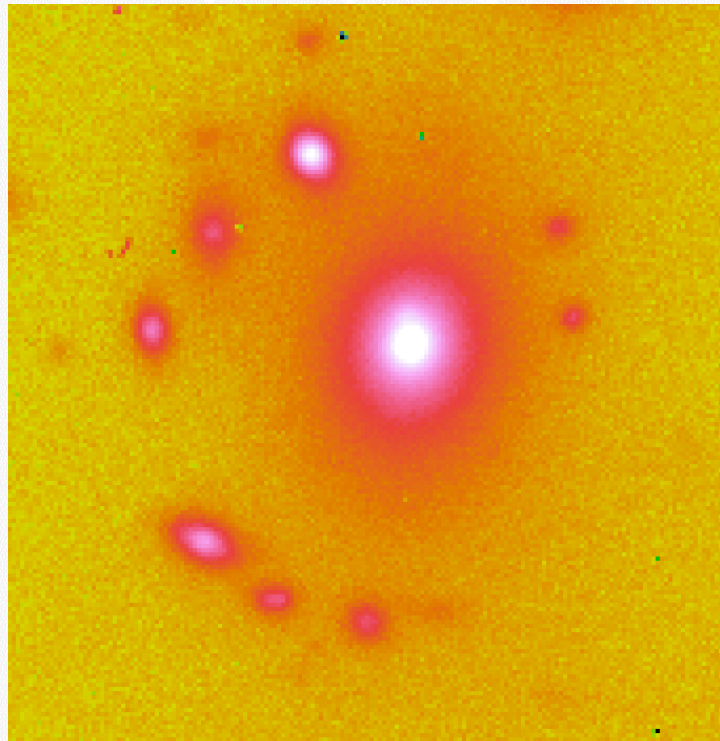




Cosmic web and underlying velocity field

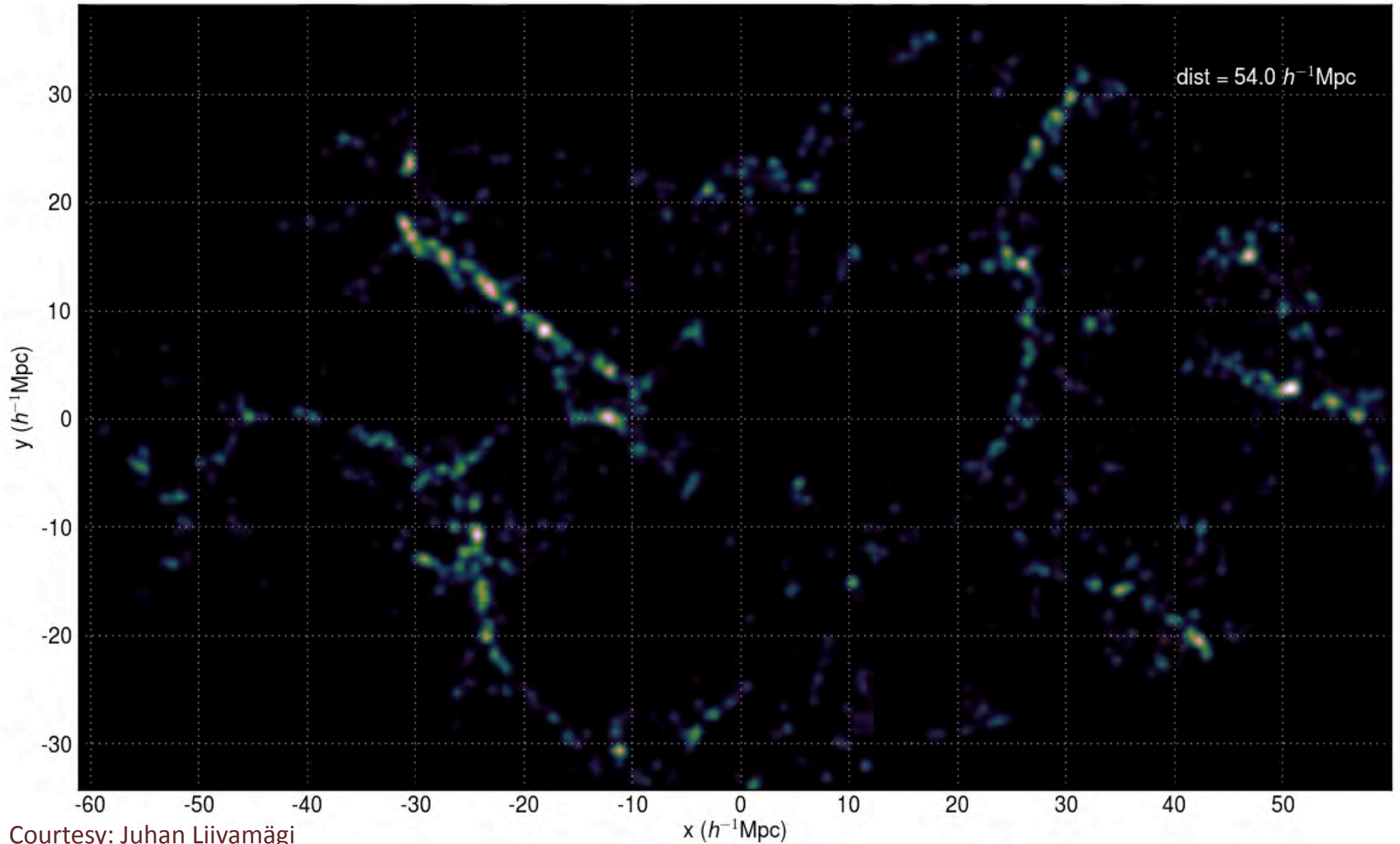
Elmo Tempel (Tartu Observatory, Estonia)



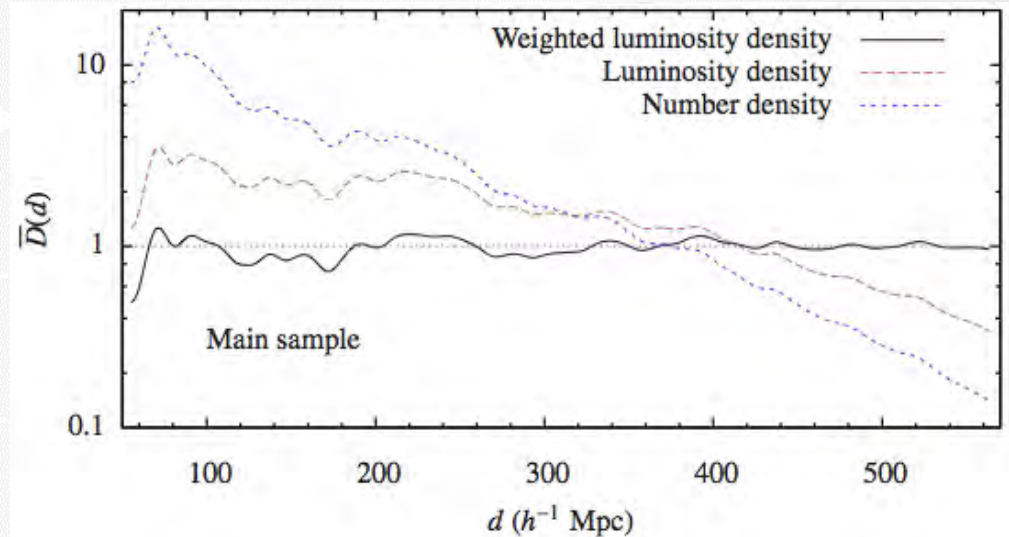
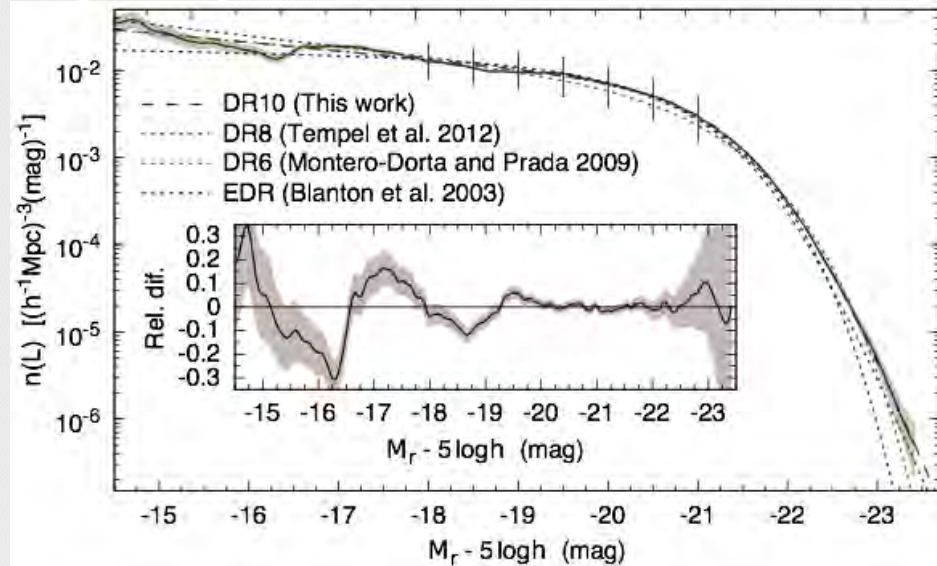
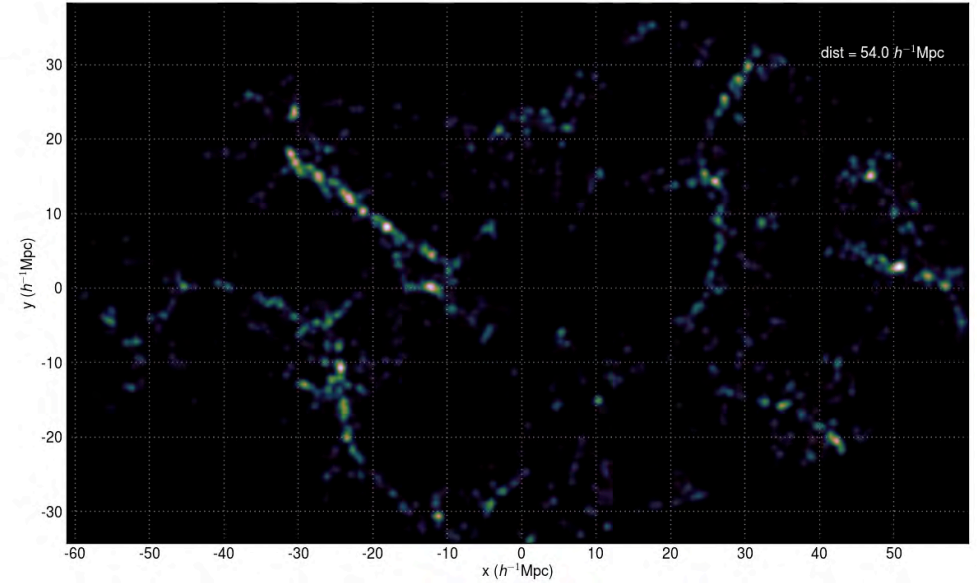
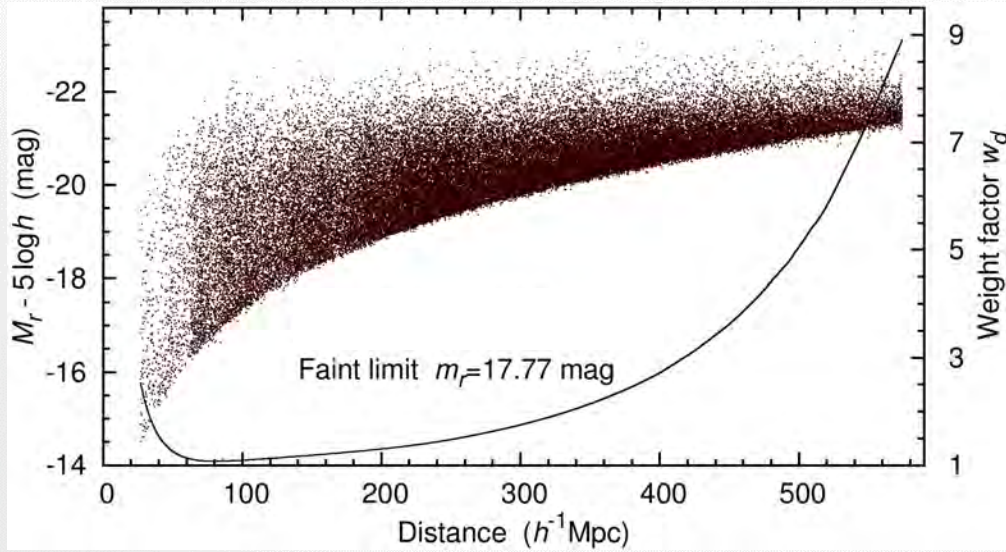
Quy Nhon, 2016



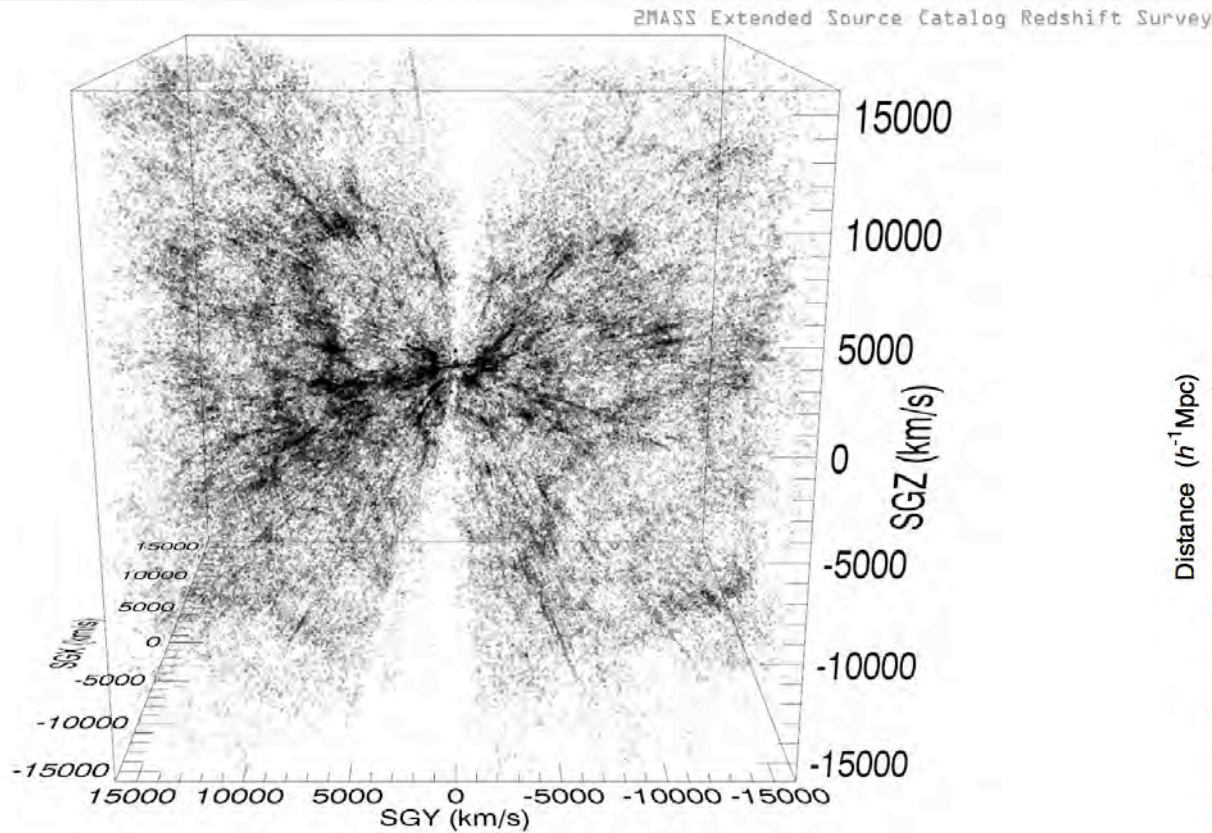
Observations: SDSS



Observations: selection effects



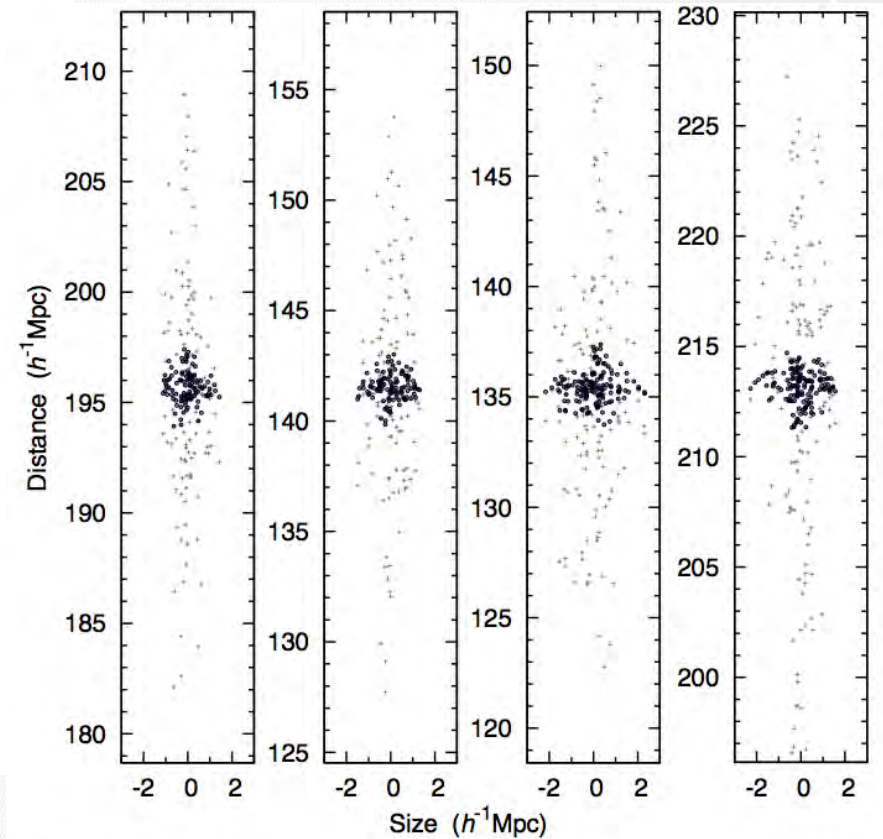
Observations: selection effects



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

Finger-of-god effect:

Tully & Fisher (1978), IAU Symposium 79,
Large Scale Structures in the Universe,
Tallinn, September 12-16, 1977

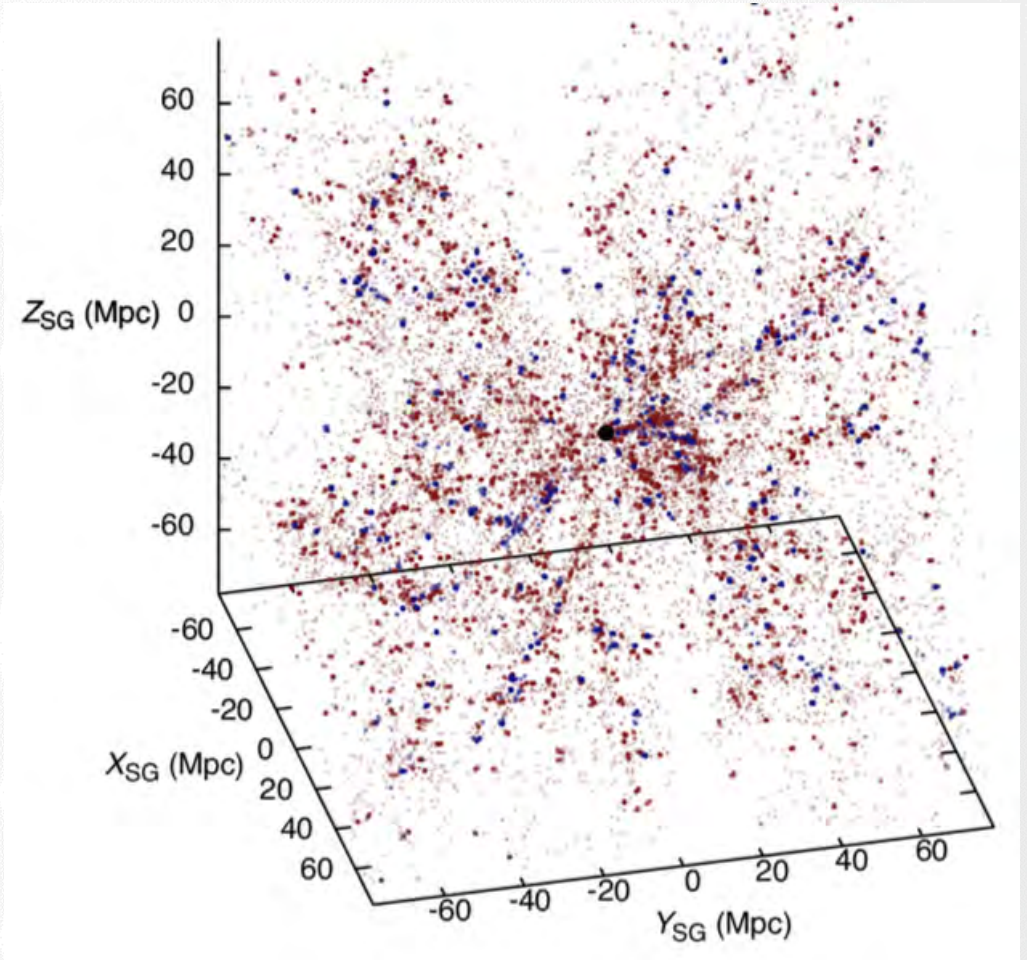
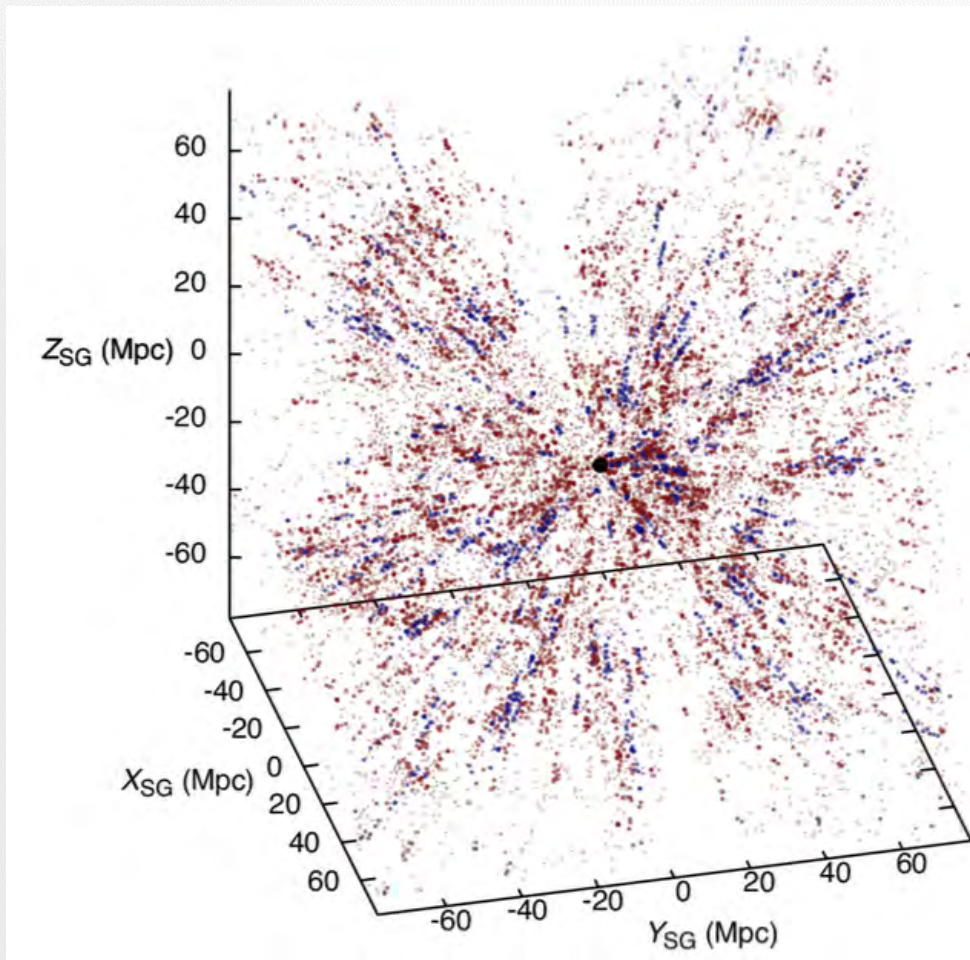


Tempel et al. (2012,2014)

Using friends-of-friends galaxy groups,
we suppress the finger-of-god distortions.



Local Universe (2MRS data)



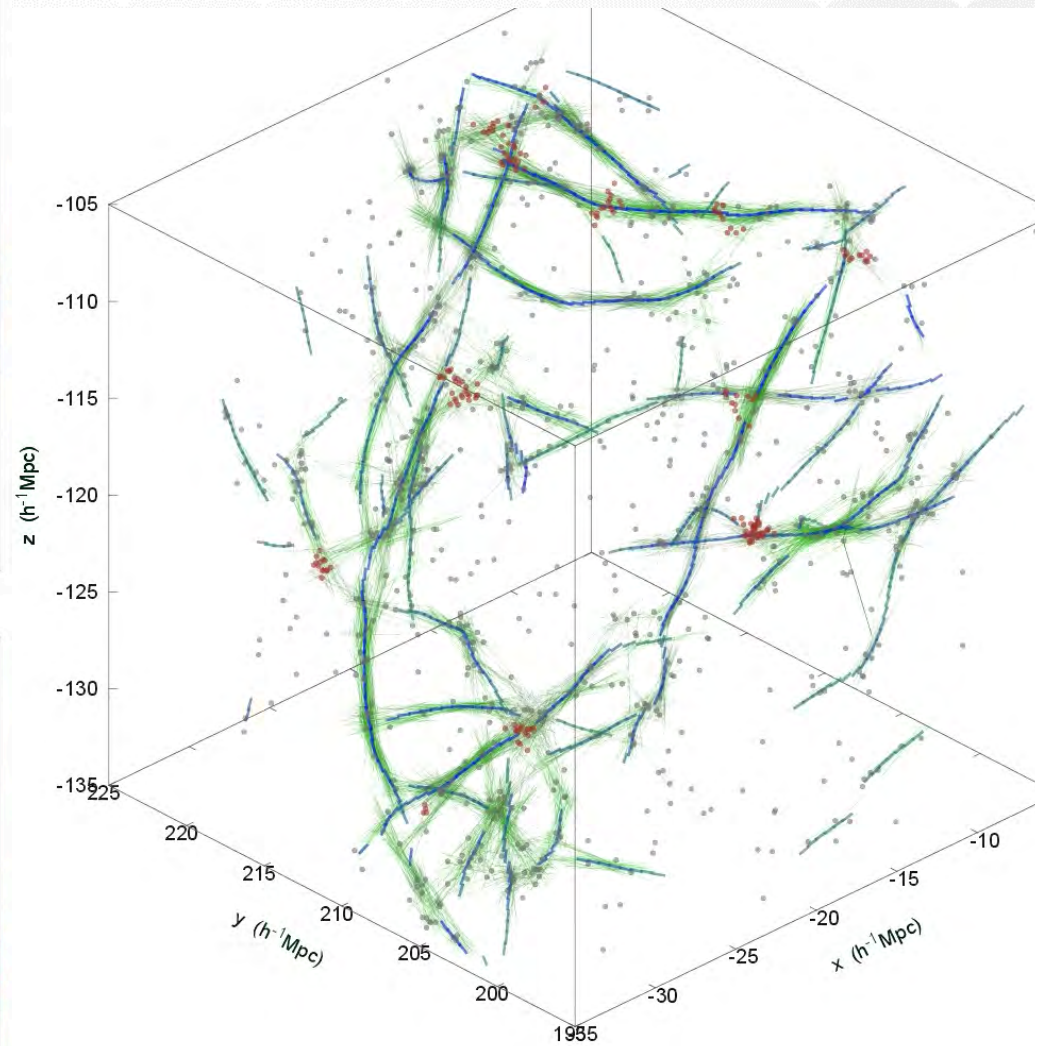
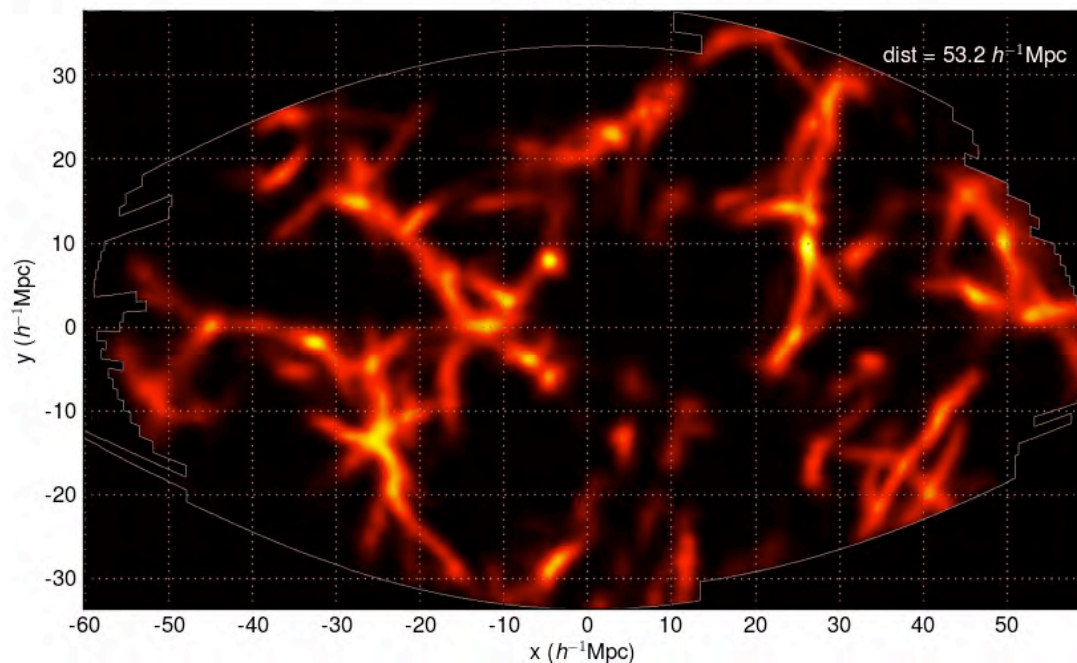
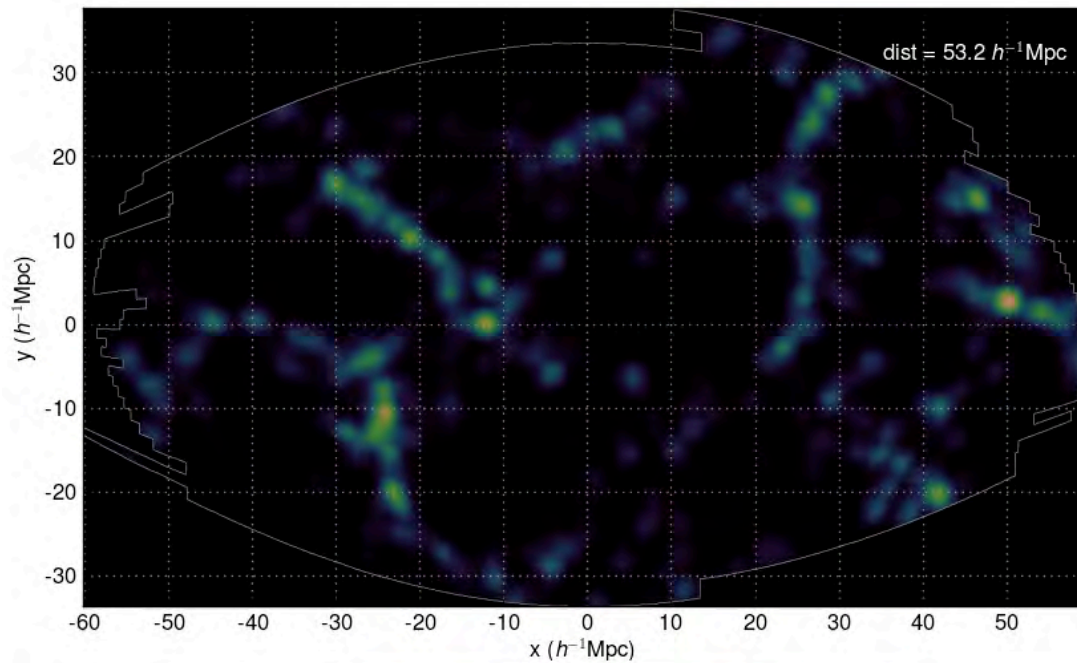
Friends-of-friends galaxy group finder with membership refinement

2016, accepted by A&A

Application to the local Universe[★]

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

Detected filamentary pattern



Tempel et al. (2014)

Courtesy: Juhan Liivamägi



Marked point process (Bisous model)

- ✦ The key idea is to see the filamentary network as an object point process.
- ✦ Cylinders are simplest objects to define a piece of filament.
- ✦ Interactions help to form a network.
- ✦ Metropolis-Hastings algorithm (together with simulated annealing) to sample probability distribution.

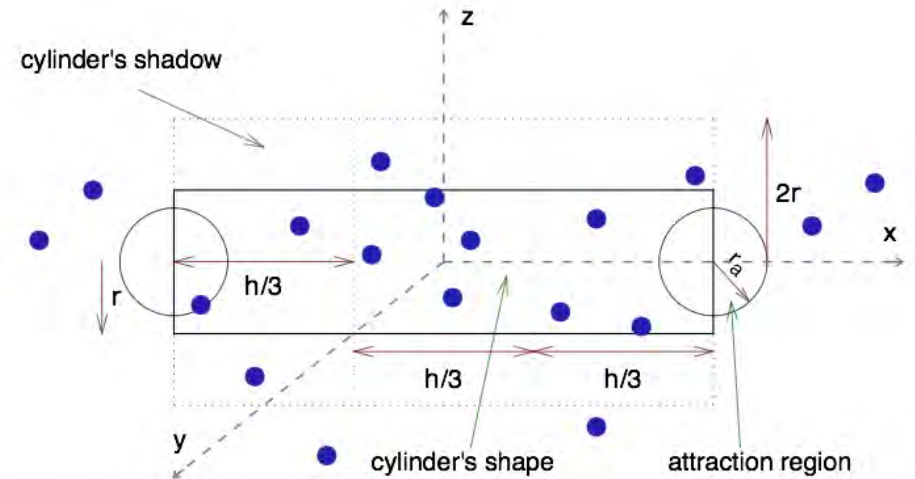


Figure 1. Two-dimensional projection of a cylinder with its shadow within a pattern of galaxies. The attraction regions are shown as spheres. The exact shape of the cylinder, its shadow and attraction regions depend on the model.

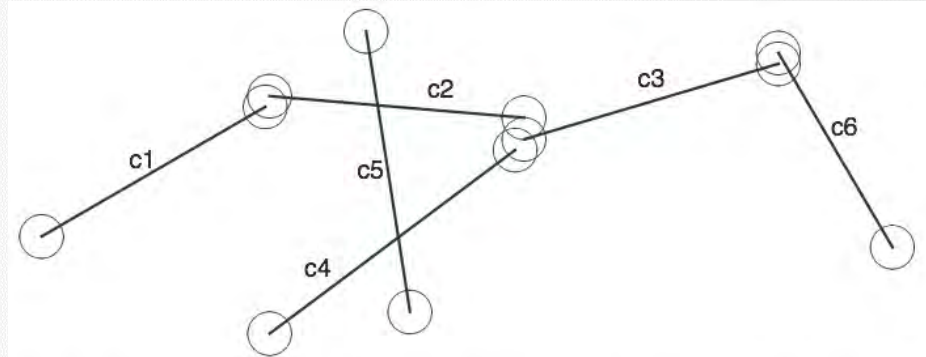


Figure 2. Two dimensional representation of cylinder configuration: attraction regions are shown with spheres. In this configura-

Stoica et al. (2003, 2005)

Stoica, Martinez, Saar (2007, 2010)

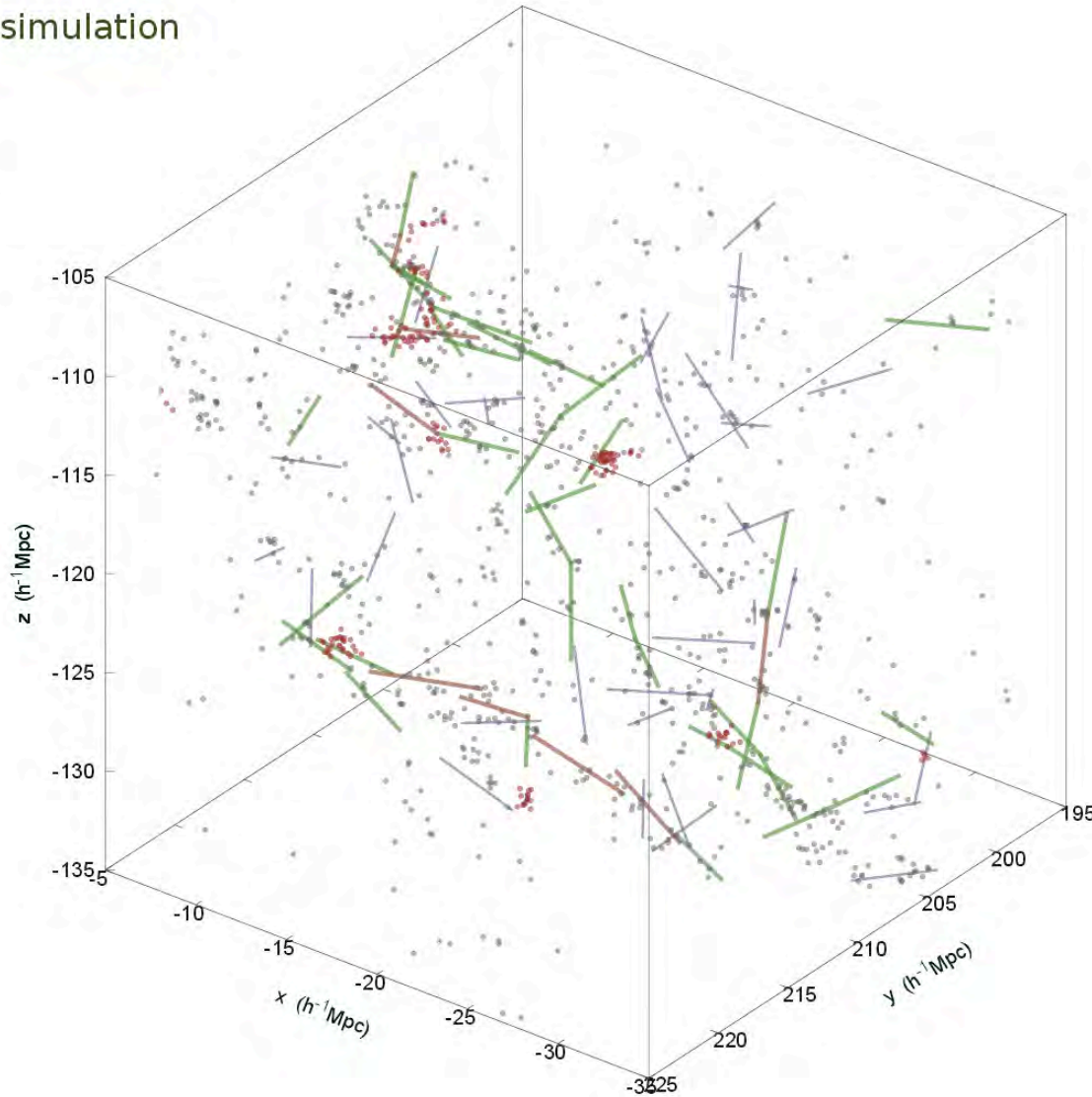
Tempel et al. (2014, 2016)



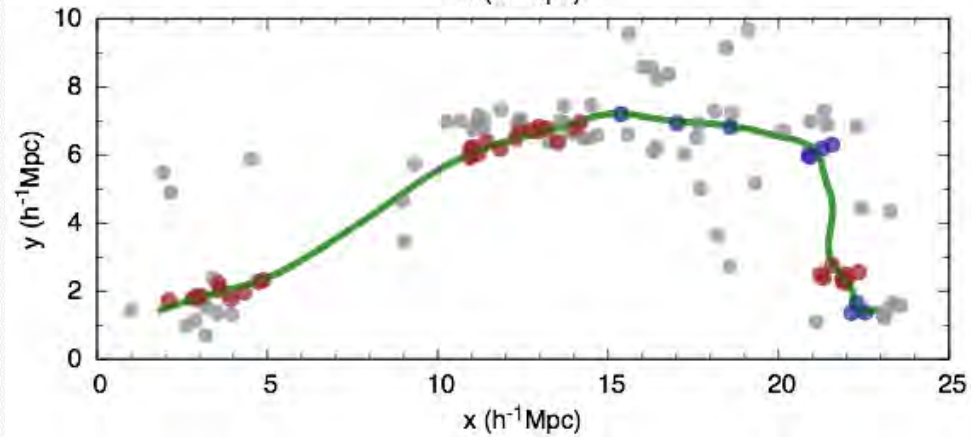
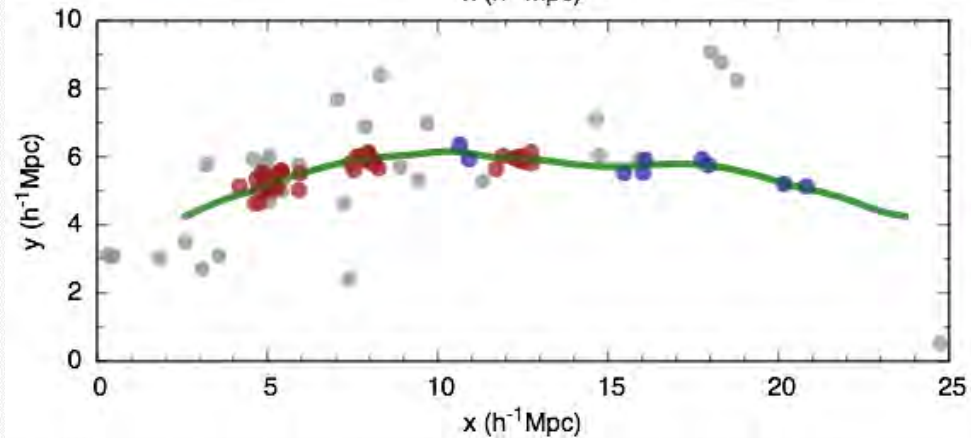
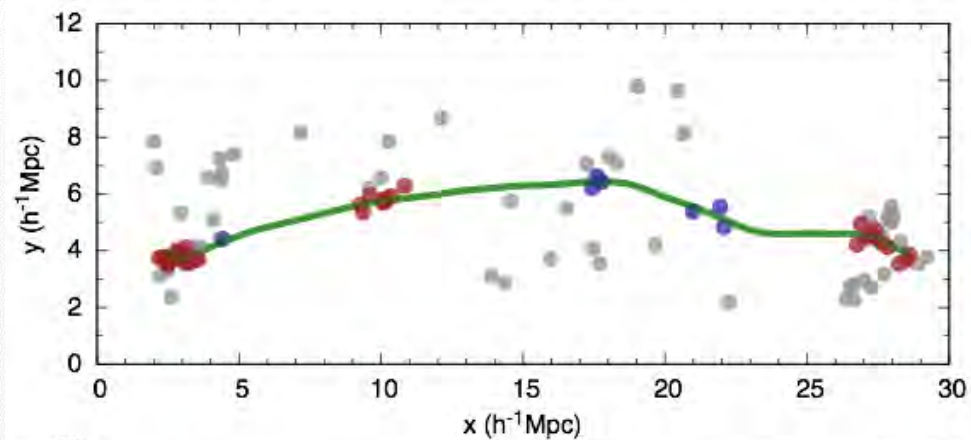
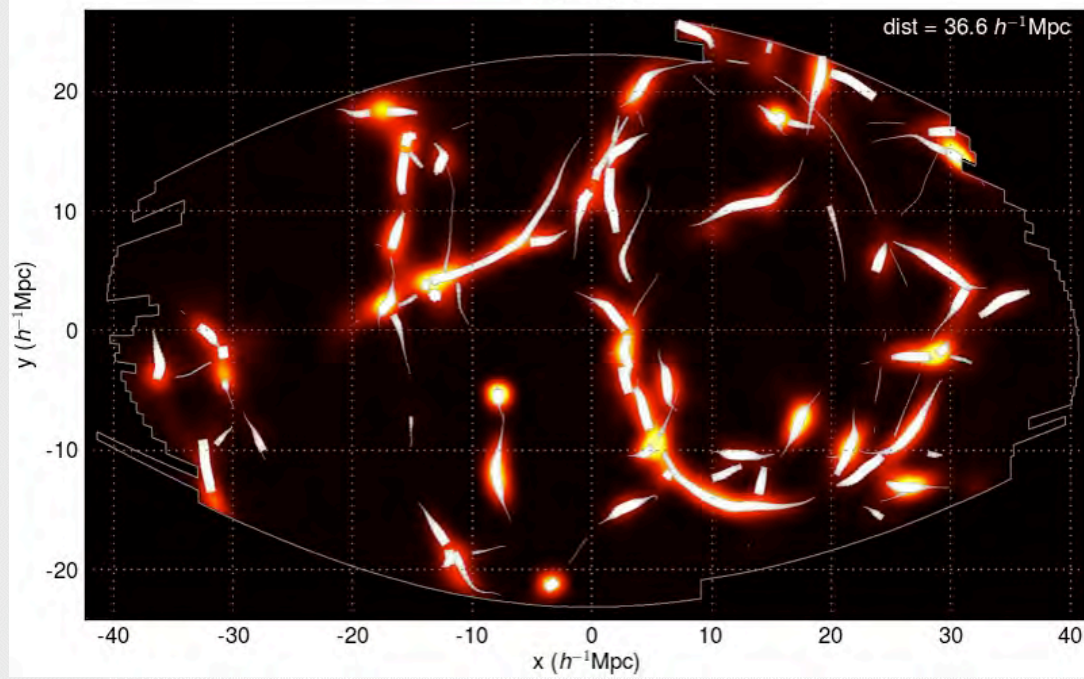
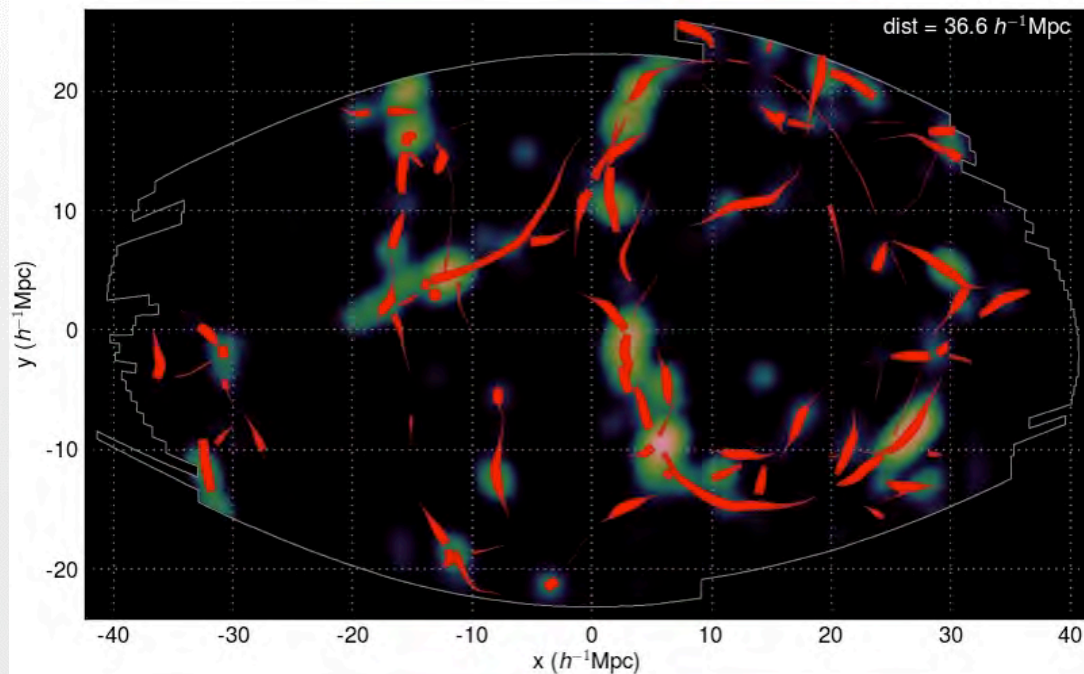
Bisous model in action

Single MCMC simulation

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



Detected filament spines





Bisous model: key questions

- ✦ What is the local definition for a filament?
- ✦ How connected is the filamentary network?
- ✦ What is the scale of galactic filaments?
- ✦ How to describe the multi-scale nature of filaments?



Bisous model - publications:

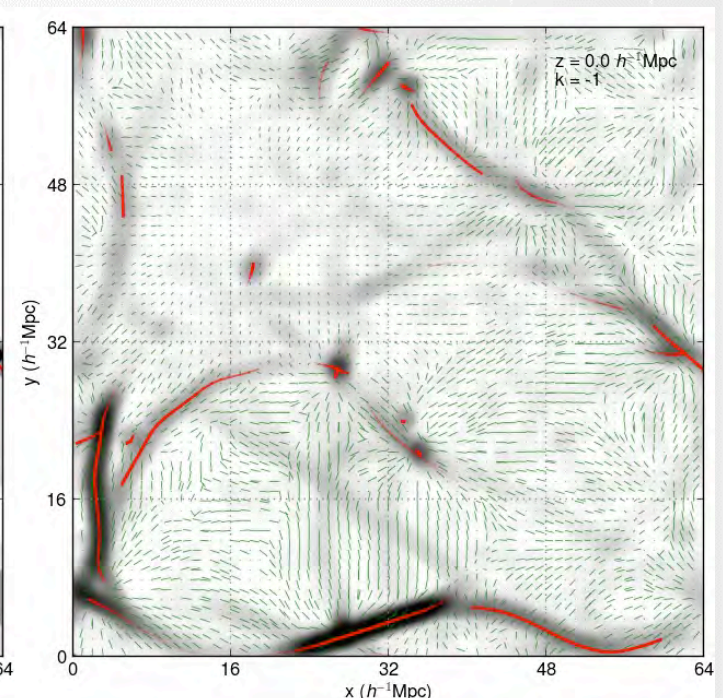
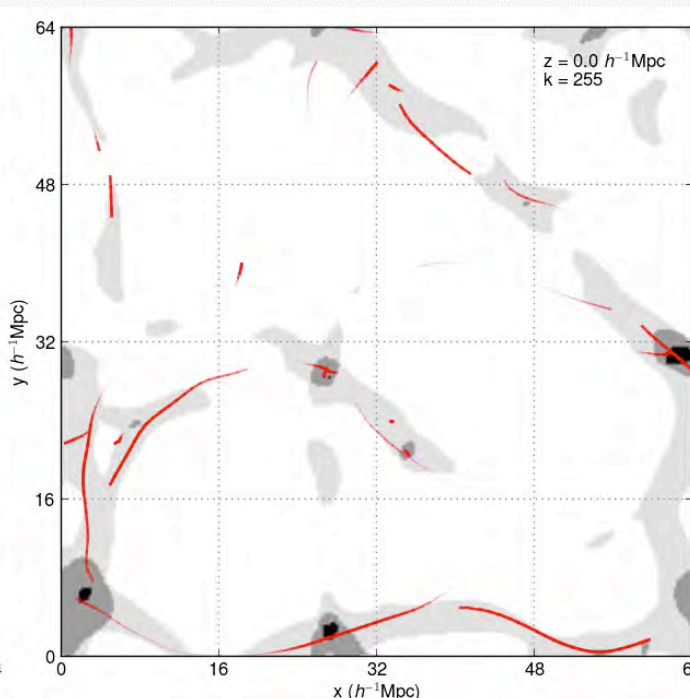
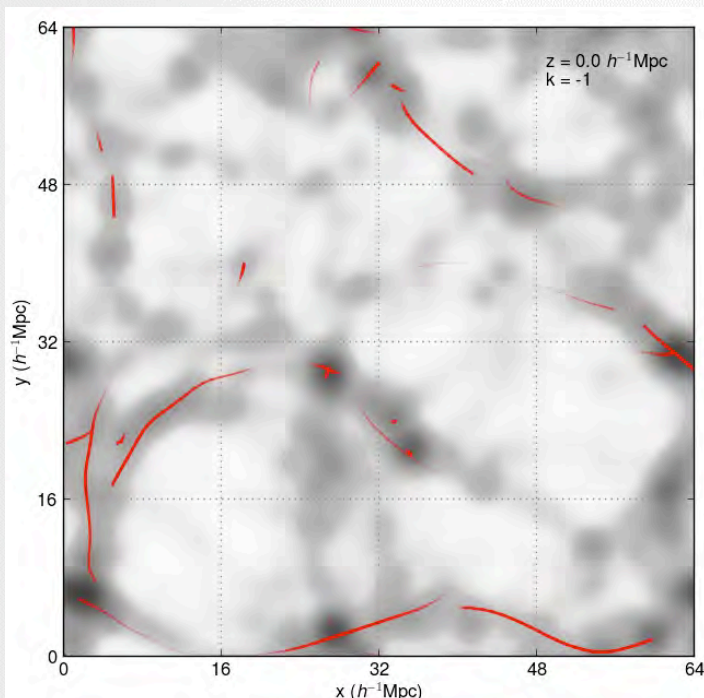
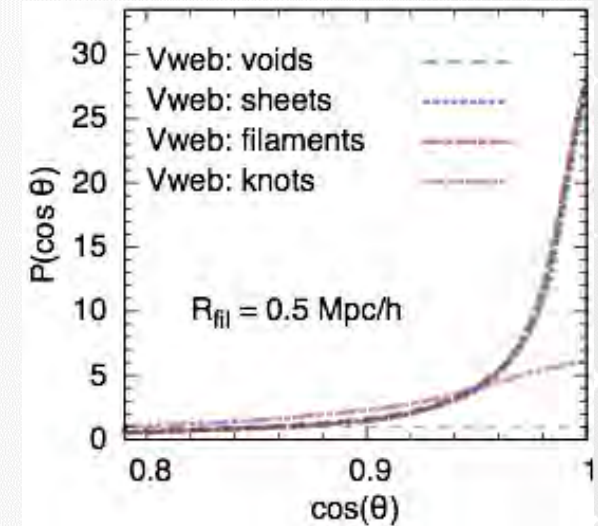
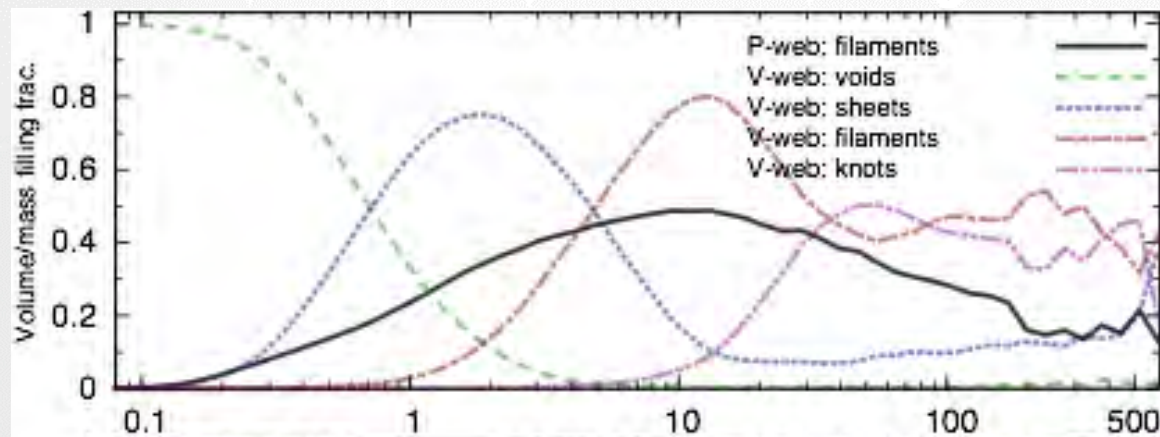
- ✦ 2013, “Evidence for spin alignment of spiral and elliptical/S0 galaxies in filaments”, (Tempel E., Stoica R. S., Saar E.; MNRAS, 428, 1827)
- ✦ 2013, “Galaxy Spin Alignment in Filaments and Sheets: Observational Evidence” (Tempel E., Libeskind N. I.; ApJL, 775, 42)
- ✦ 2014, “Orientation of cosmic 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)



Filaments and underlying velocity field

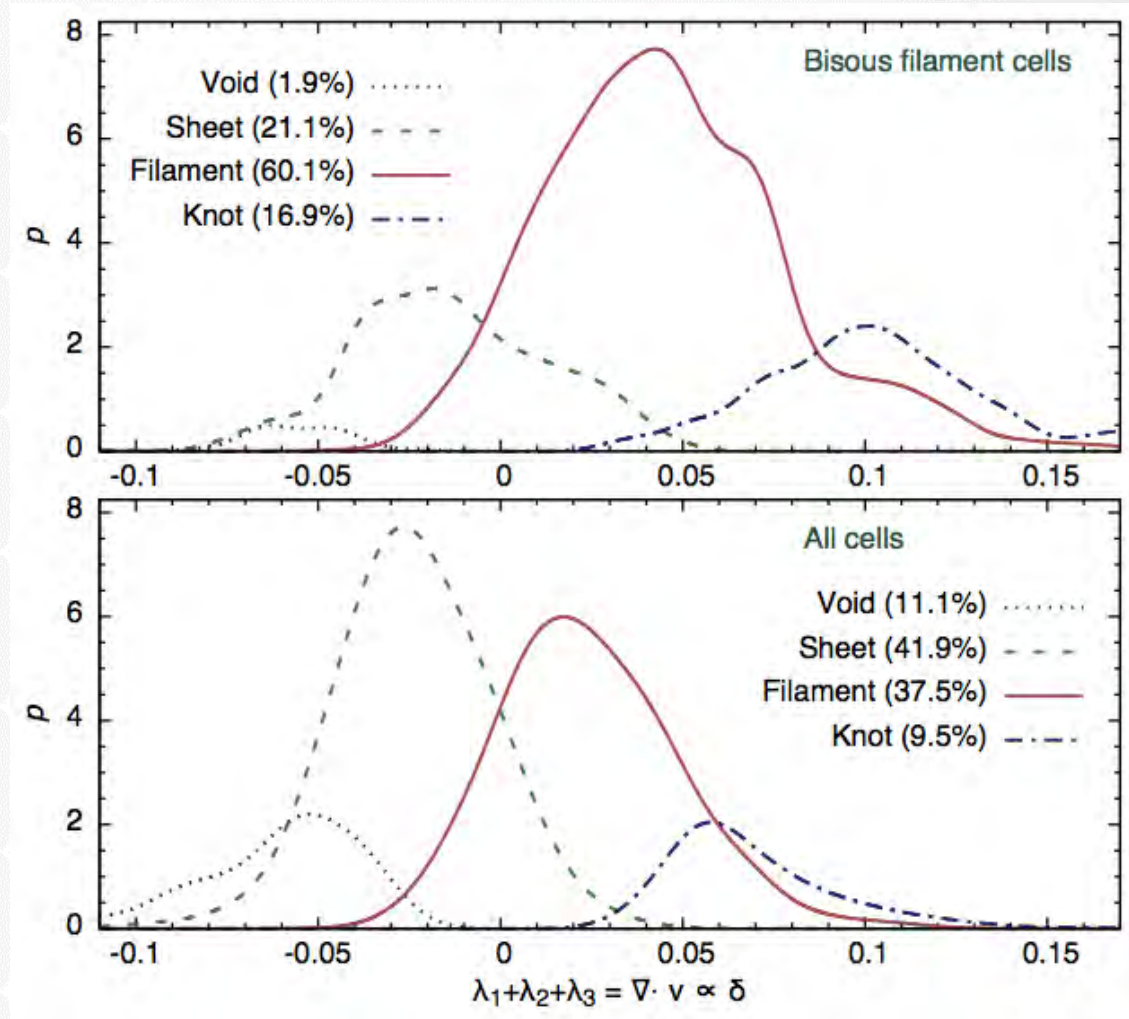
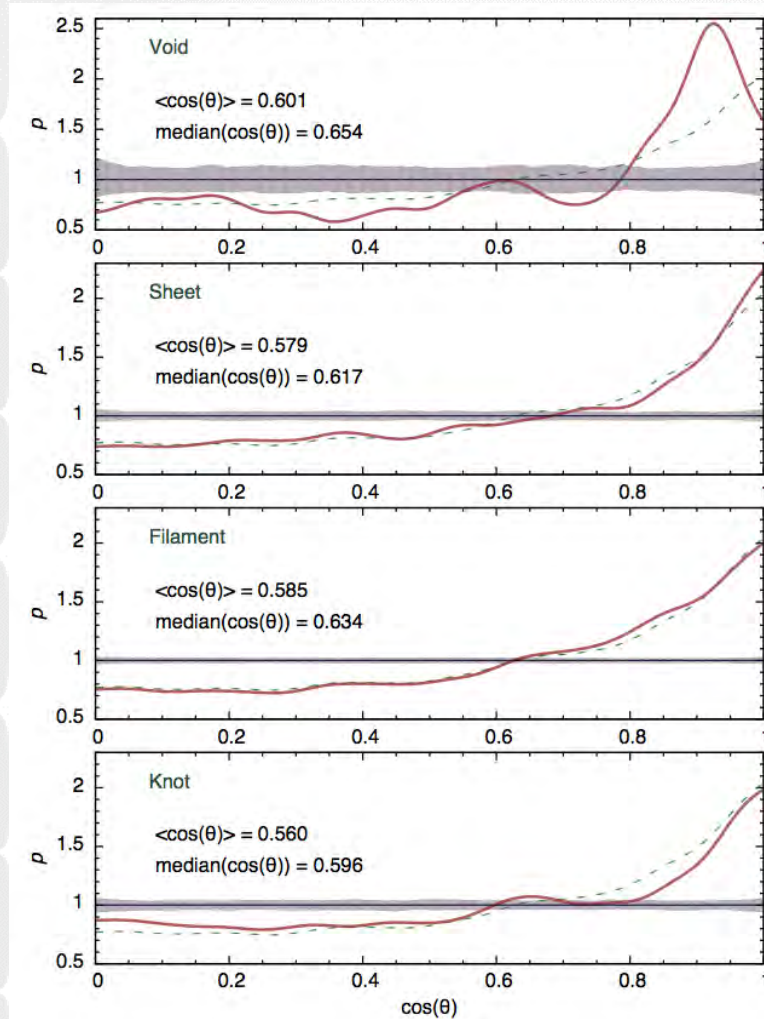
Orientation of cosmic web filaments with respect to the underlying velocity field

Tempel, Libeskind, Hoffman et al. (2014)



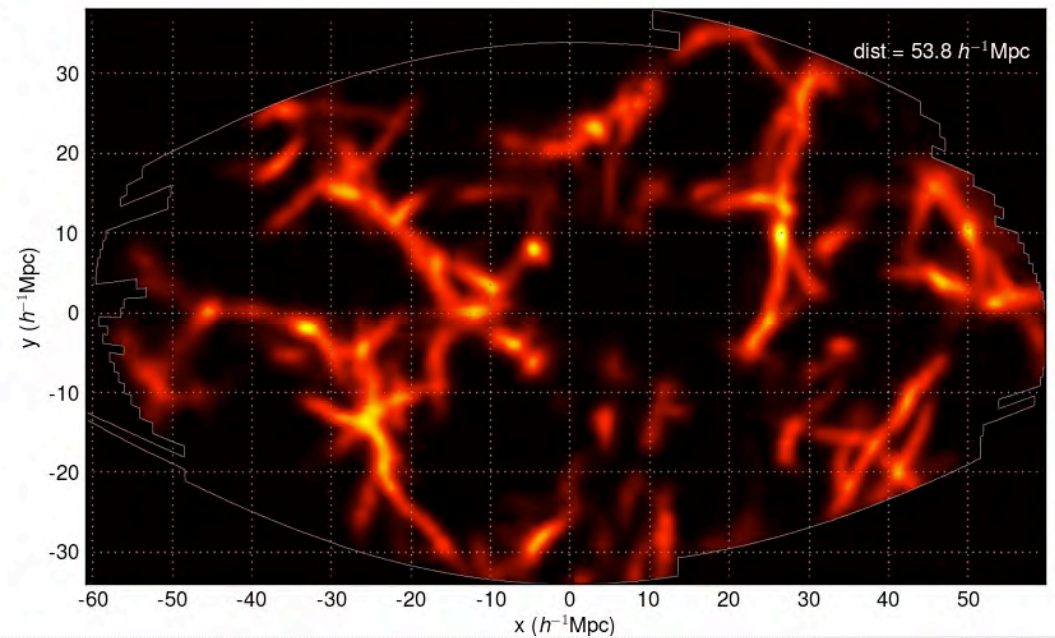
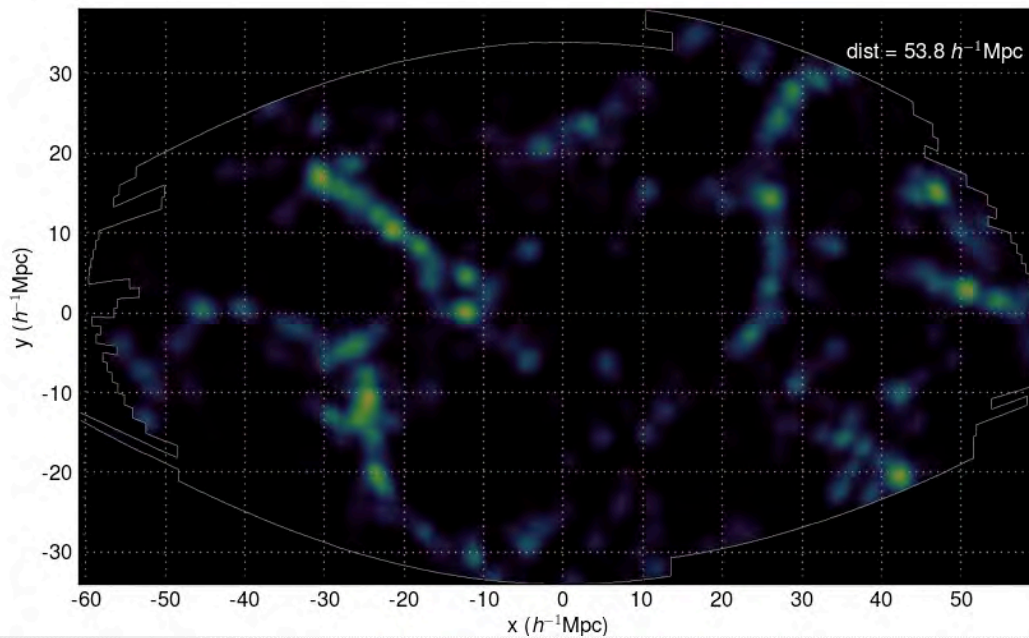
Filaments from the galaxy distribution and from the velocity field in the local universe

Libeskind, Tempel, Hoffman et al. (2015)





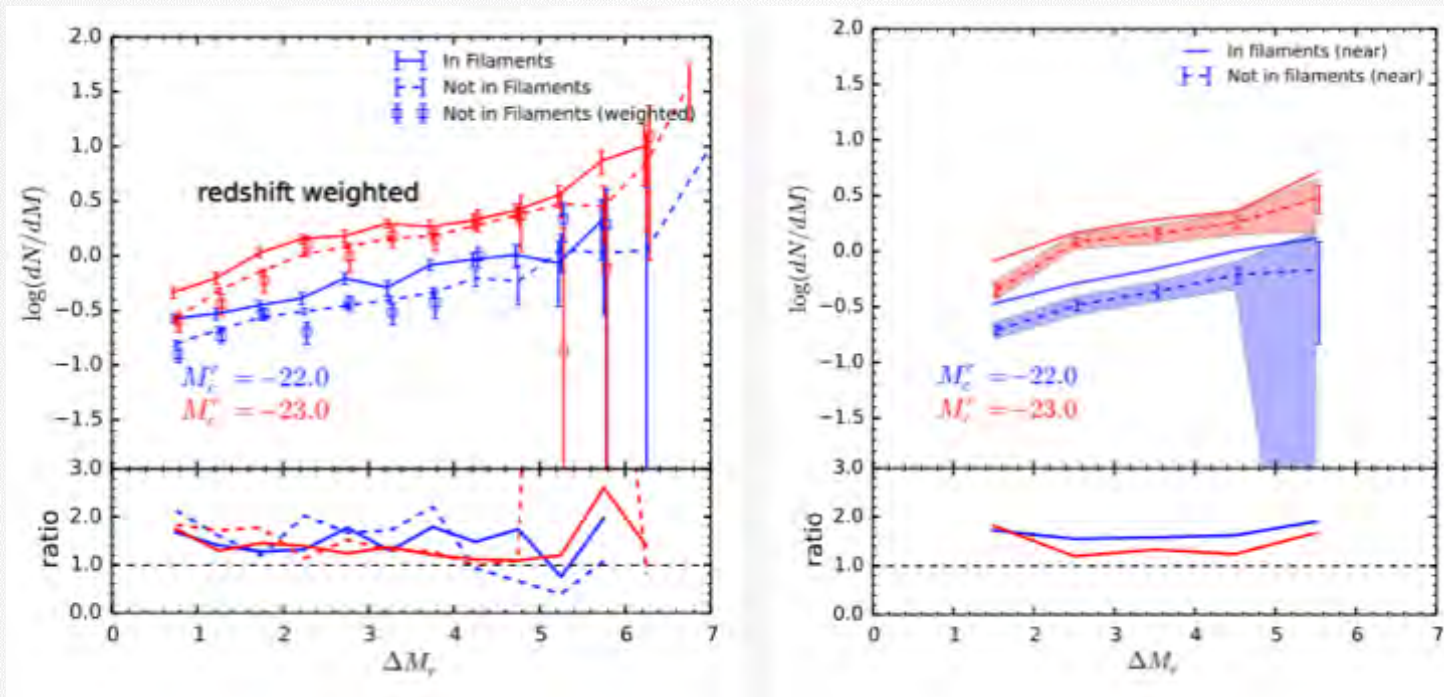
The alignment of galaxies in filaments



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

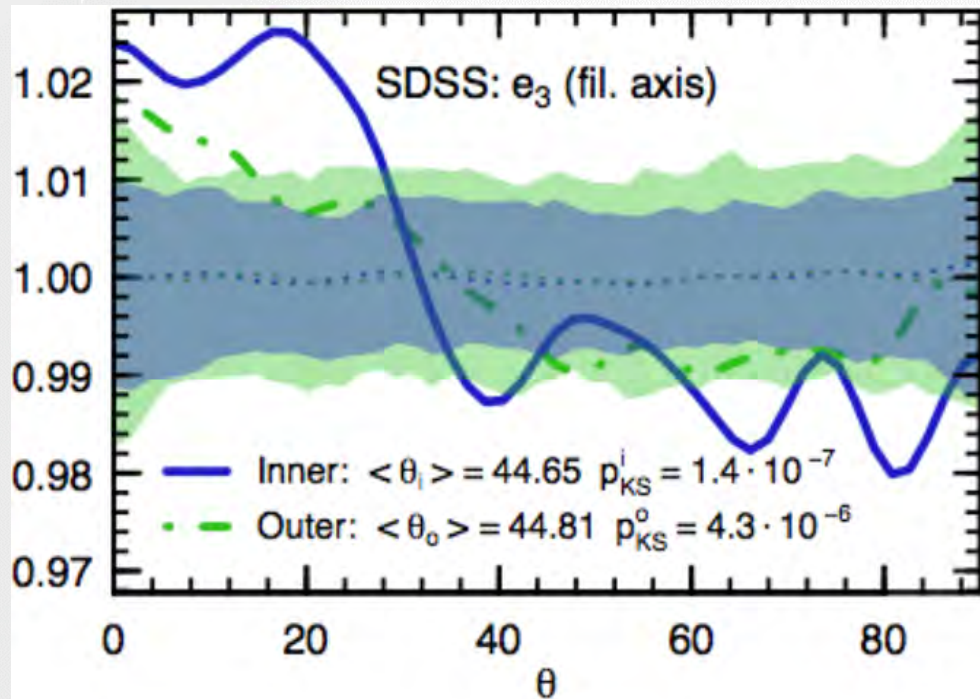


Satellite luminosity with respect to central galaxy

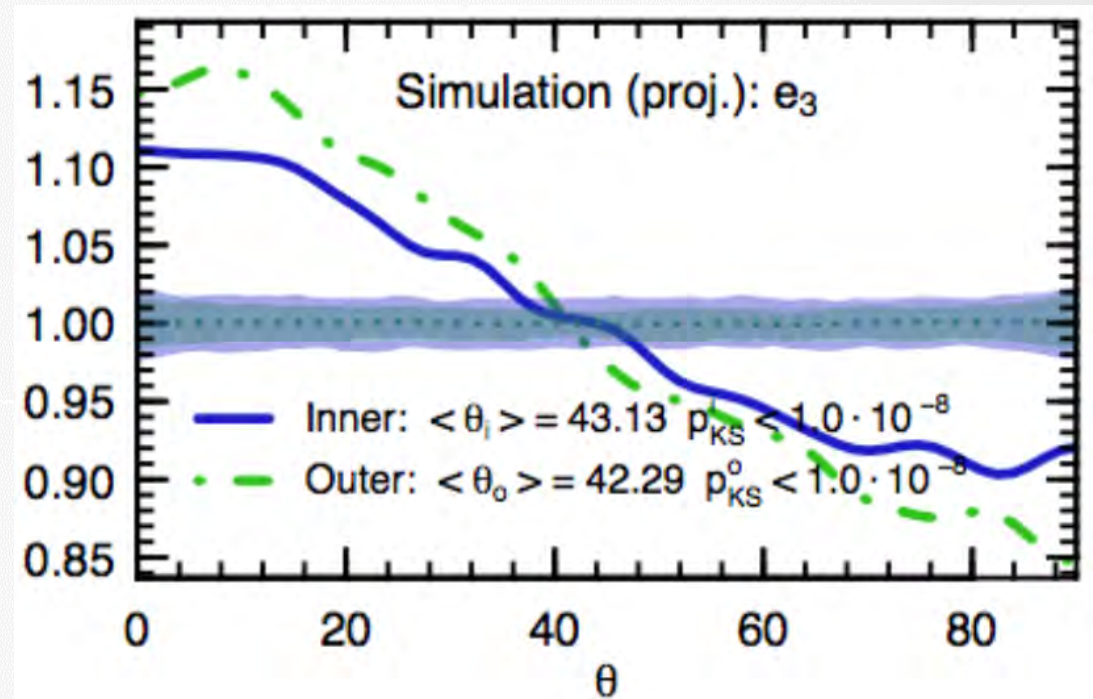
The alignment of satellite galaxies and cosmic filaments: observations and simulations

Tempel, Guo, Kipper, Libeskind (2015)

SDSS observations



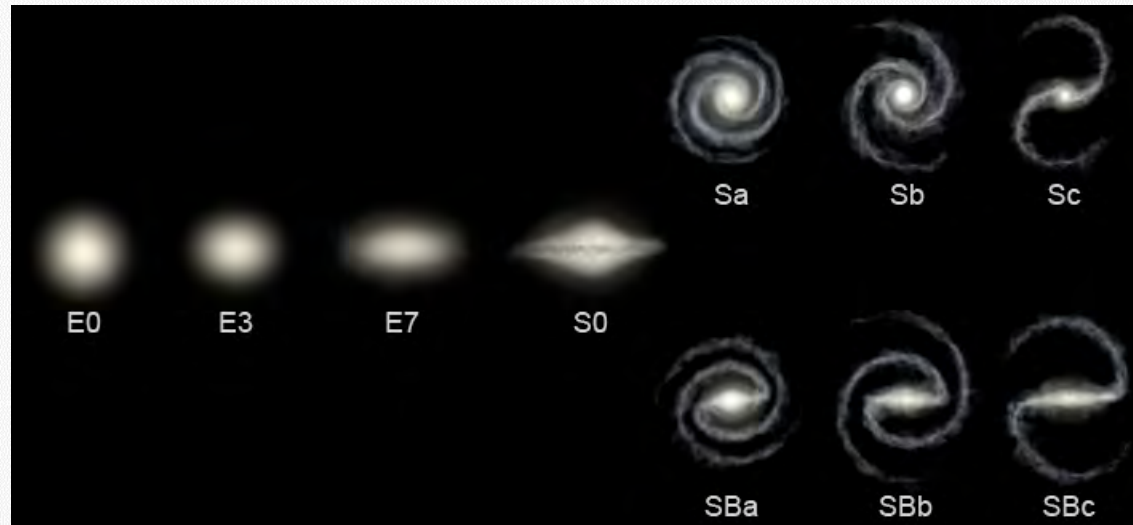
Millennium simulation



Angle between the satellite position and filament axis

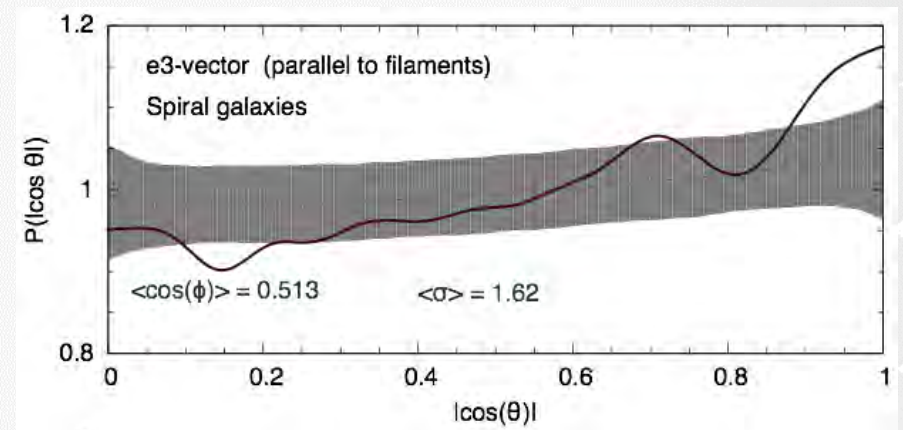
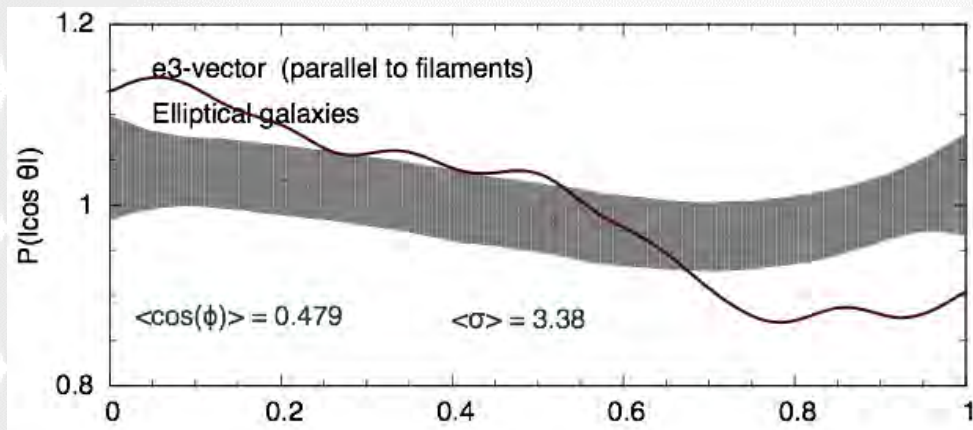
Galaxy Spin Alignment in Filaments: Observational Evidence

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



Elliptical galaxies

Spiral galaxies



Galaxy pairs align with galactic filaments

Tempel & Tamm (2015)

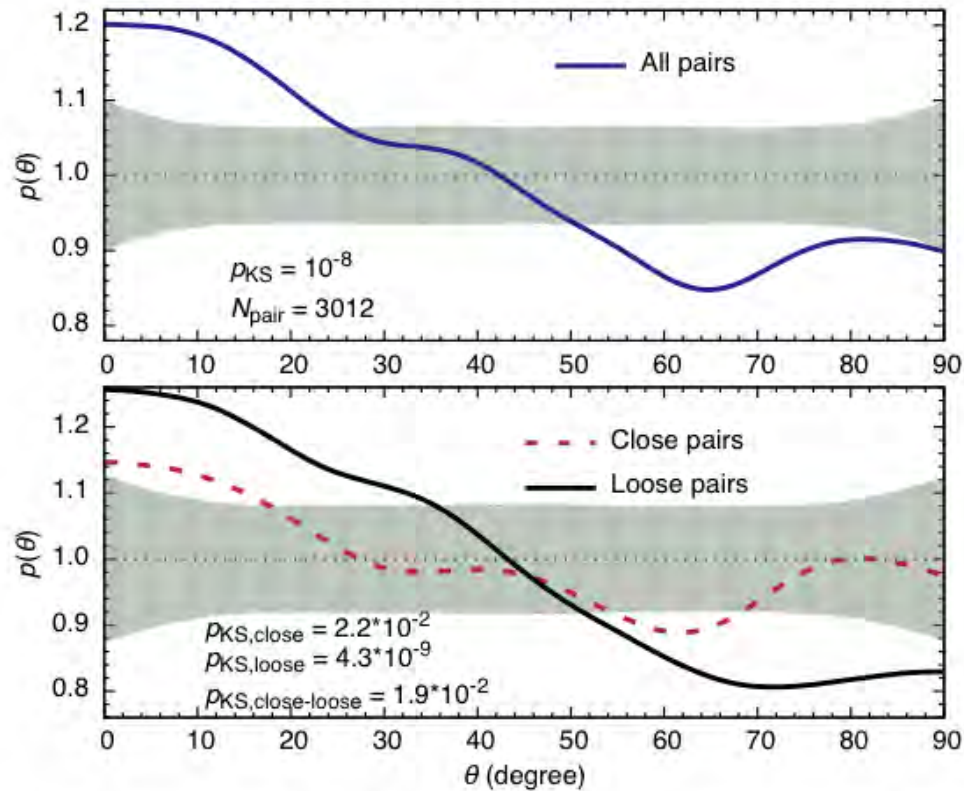
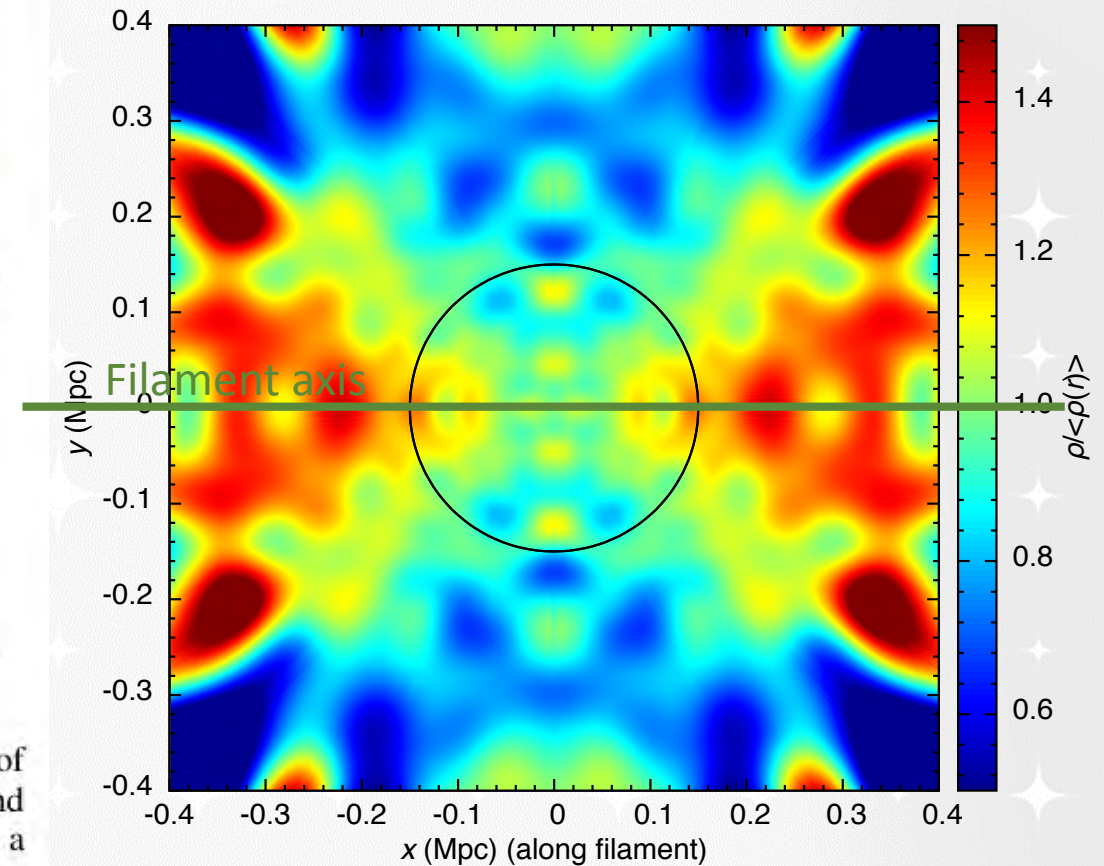


Fig. 2. *Upper panel:* probability distribution function (blue solid line) of the projected (in the plane of the sky) angles between galaxy pairs and their host filaments. The KS-test value that the sample is drawn from a uniform distribution is 10^{-8} . The filled area shows the 95% confidence region 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).





TARTU OBSERVATORY
space research centre



THE LOPSIDED DISTRIBUTION OF SATELLITE GALAXIES

NOAM I. LIBESKIND AND QUAN GUO

Leibniz-Institut für Astrophysik, Potsdam, An der Sternwarte 16, 14482 Potsdam, Germany

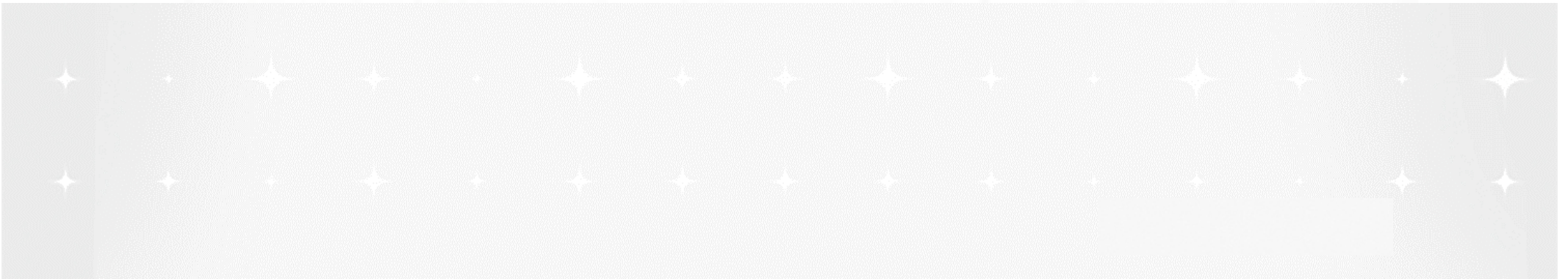
ELMO TEMPEL

Tartu Observatory, Observatooriumi 1, 61602 Tõravere, Estonia

AND

RODRIGO IBATA

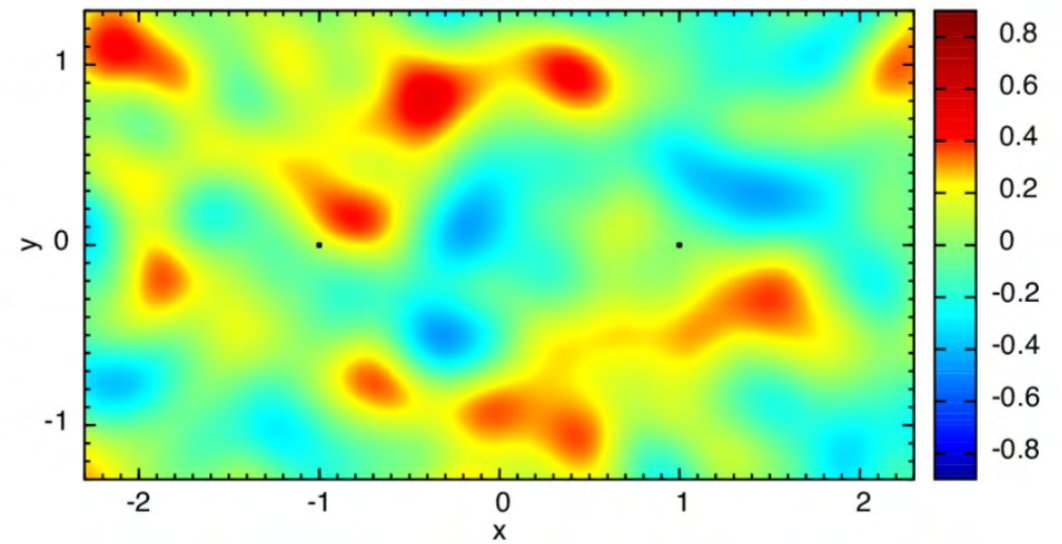
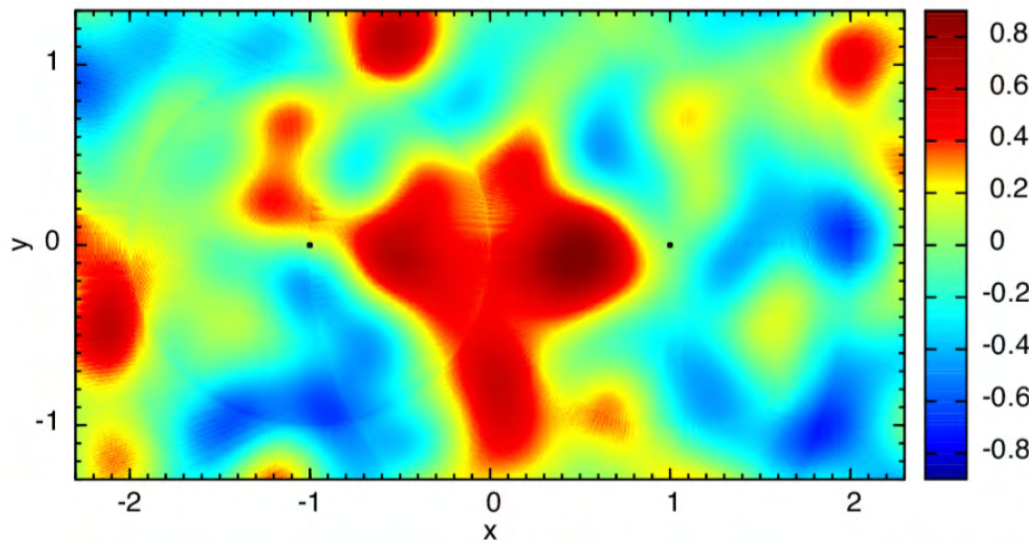
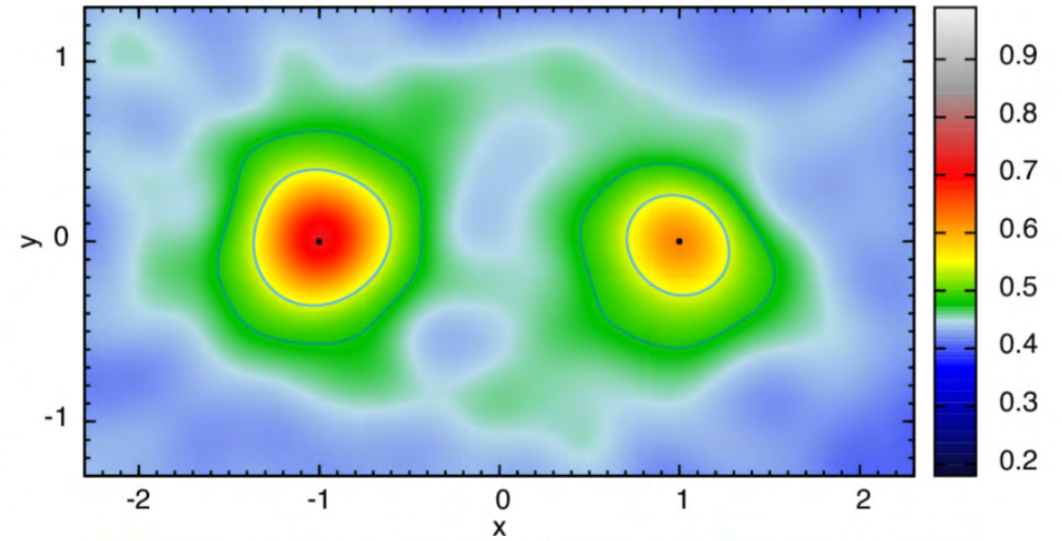
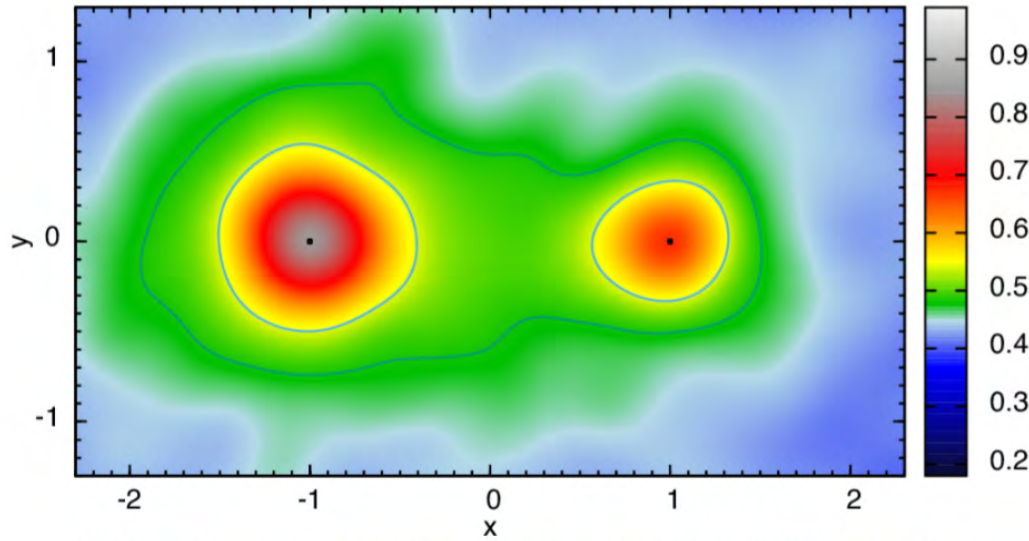
Observatoire astronomique de Strasbourg, Université de Strasbourg,
CNRS, UMR 7550, 11 rue de l'Université, F-67000 Strasbourg, France

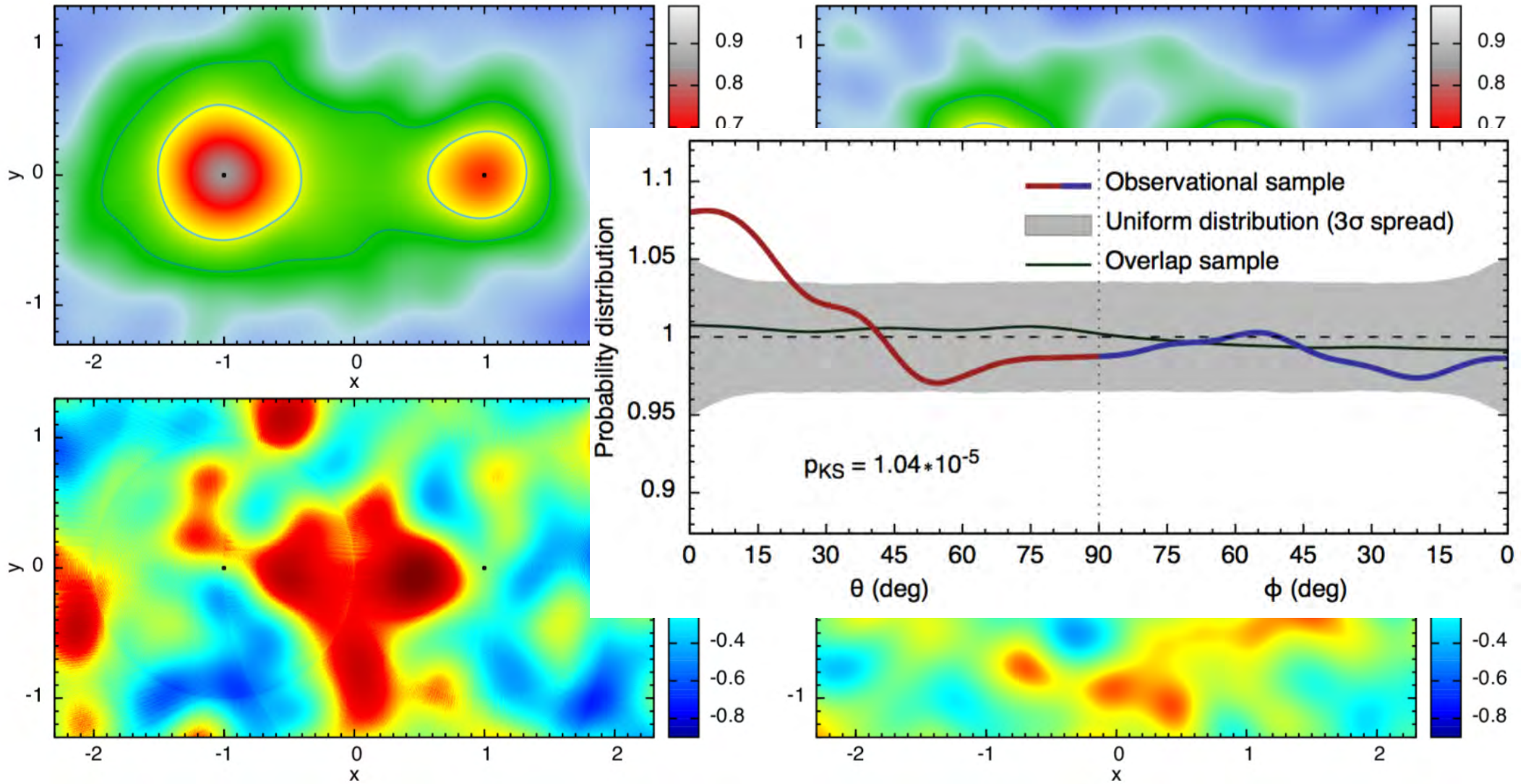




Observed galaxy pairs

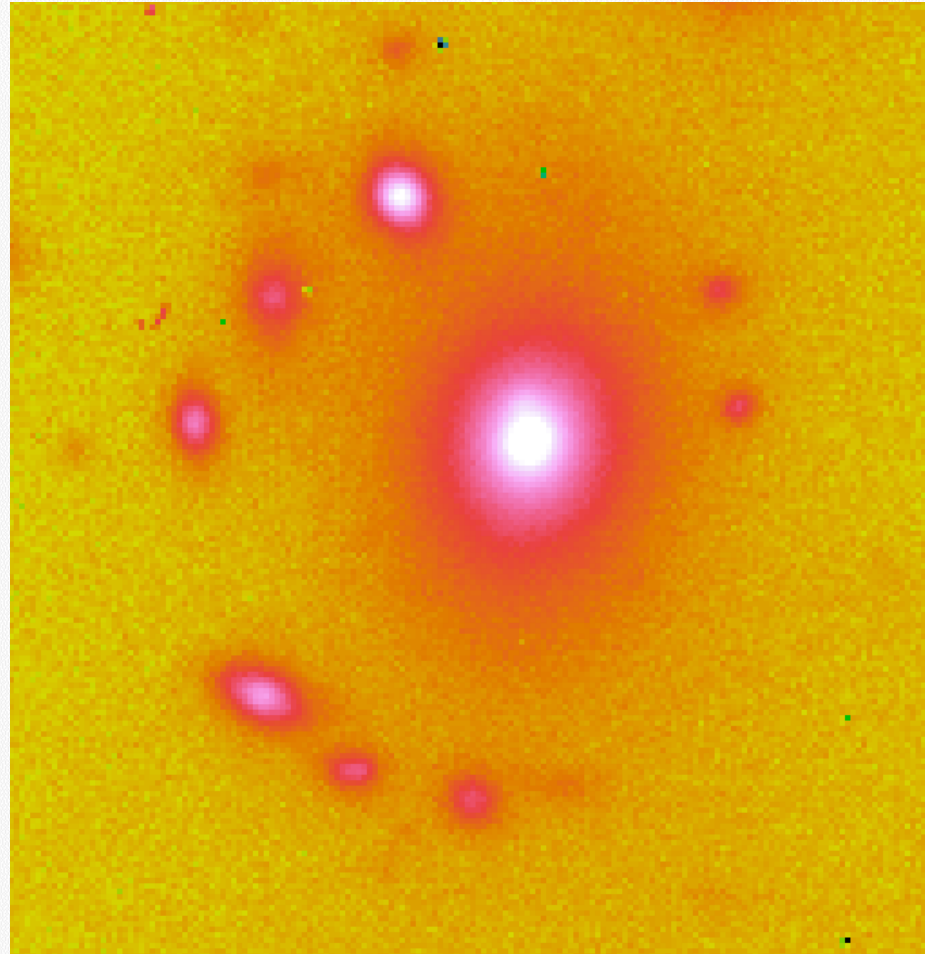
Artificial galaxy pairs







Riddle — What is in the image?



Thank you!