Bisous model — detecting filamentary pattern in the cosmic web: applications

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Outline

- Detecting filamentary pattern spine in the galaxy distribution.
- Probabilistic approach: marked point process (Bisous model) to detect the filamentary network.
  

- Applications of Bisous model
  
  arXiv:1406.4357 “Galaxy filaments as pearl necklaces”
  arXiv:1403.5563 “Galaxies in filaments have more satellites: the influence of the cosmic web on the satellite luminosity function in the SDSS”
  arXiv:1307.1232 “Orientation of cosmic web filaments with respect to the underlying velocity field”
  arXiv:1308.2816 “Galaxy spin alignment in filaments and sheets: observational evidence”
  arXiv:1207.0068 “Evidence for spin alignment of spiral and elliptical/S0 galaxies in filaments”
  in prep. “The alignment between anisotropic distribution of satellites and the direction of filaments”
  in prep. “Filaments in the SDSS: galaxy content”
  in prep. All other ideas...
Observations: SDSS

dist = 54.0\, h^{-1}\text{Mpc}

Courtesy: Juhan Liivamägi
Observations: selection effects (1)

Tempel et al. (2012, 2014)

Liivamägi, Tempel, Saar (2012)
Observations: selection effects (2)

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

Finger-of-god effect:

Tempel et al. (2012)

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.

Stoica et al. (2003, 2005)
Stoica, Martinez, Saar (2007, 2010)
Tempel et al. (2014), arxiv:1308.2533
Bisous model in action
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?
Extracting filament spines

- Bisous model: set of simulations (50 simulations)
- Many independent realisations in every simulation
- Density field of filaments
- Orientation field of filaments
- Single filament spines
Detected filament spines
A catalogue of filaments for the SDSS

Tempel et al. (2014), arxiv:1308.2533
http://cosmodb.to.ee
Applications of filamentary network
Orientation of cosmic web filaments with respect to the underlying velocity field

Tempel, Libeskind, Hoffmann et al. (2014)
Galaxy Spin Alignment in Filaments: Observational Evidence

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

Spiral galaxies

Elliptical galaxies

Inner part

Outer part
Galaxy Spin Alignment in Sheets: Observational Evidence

Tempel & Libeskind (2013)
Galaxy Spin Alignment in Sheets: Observational Evidence
Tempel & Libeskind (2013)
Galaxy Spin Alignment: Dependence on environment (in prep)
Galaxies in filaments have more satellites: the influence of the cosmic web on the satellite luminosity function in the SDSS

Quo, Tempel & Libeskind (2014)
The alignment between anisotropic distribution of satellites and the direction of filaments

Quo, Tempel & Libeskind (in prep.)

Preliminary!
Filaments in the SDSS: galaxy content

(in prep.)
Galaxy filaments as pearl necklaces

Tempel et al. (2014), arXiv:1406.4357
Data and methods

Pair correlation function:

\[ \xi(r) = 1 + \frac{DD(r)}{RR(r)} - 2 \frac{DR(r)}{RR(r)}, \]

Rayleigh Z-squared statistics:

The algorithm works as following. For each filament, we produce a periodogram using the \( Z^2_1 \) (Rayleigh statistics),

\[ Z^2_1 = \frac{2}{N} \left[ \left( \sum_{j=1}^{N} \cos \phi_j \right)^2 + \left( \sum_{j=1}^{N} \sin \phi_j \right)^2 \right], \tag{4} \]

where \( N \) is the number of galaxies in a filament and \( \phi_j = 2\pi l_j/d \) is the phase value for a galaxy \( j \) for a fixed period \( d \); \( l_j \) is a galaxy \( j \) distance along the filament spine from the beginning of the filament.
Pair correlation function along filaments

**Galaxies**

- **All filaments**
- **Filaments parallel to the line of sight**
- **Filaments perpendicular to the line of sight**

**Groups**

- **Groups: \(N_{\text{gal}}\geq 1\)**
- **Groups: \(N_{\text{gal}}\geq 2\)**
- **Groups: \(N_{\text{gal}}\geq 3\)**
Fig. 7. The Rayleigh ($Z$-squared) statistic $Z_i^2$ for a given distance (period). The upper panel shows the results for galaxies closer than $0.5\ h^{-1}\text{Mpc}$ to the filament axis and the lower panel shows the results for galaxies closer than $0.25\ h^{-1}\text{Mpc}$. The red line shows the $Z_i^2$ statistics together with the jackknife 95% confidence estimate. The blue line shows the results from Monte Carlo simulations for the null hypothesis together with the 95% confidence limits.
Summary

- We developed a probabilistic model for filamentary network detection, based on marked point processes (the Bisous model).
- We applied the Bisous model to the SDSS dataset and generated a catalogue of filaments (http://cosmodb.to.ee).
- We studied the distribution of galaxies/groups along filaments and showed that they tend to form a regular pattern. The characteristic length of the pattern is about 7 Mpc/h.
- We propose that this well-defined characteristic scale could be used as a cosmological test.
(some) ideas for the (near) future
to be filled...
**Fig. 3.** The pair correlation function of galaxies along filaments. Various correlation function estimators are shown: Davis & Peebles (1983) (green line), Hamilton (1993) (blue line), and Landy & Szalay (1993) (red line). The black line shows the integral constraint corrected correlation function computed using the Landy-Szalay estimator.

**Fig. 4.** The $Z^2$-squared statistics for three cases. The green line shows the $Z^2$-squared statistic for a Poisson sample. The blue line shows the statistic for a periodic signal, where the period for each datapoint is drawn from a Gaussian distribution centred at 7 $h^{-1}$ Mpc with a standard deviation of 0.5 $h^{-1}$ Mpc. The red line shows the statistic for data points for a uniform point distribution – see text for more information.