Perseus cluster, Euclid first images

Observed Cosmic Web (Tempel lectures)

- Cosmic Web as revealed in observations

- Galaxy redshift surveys - biased overview

- 4MOST WAVES and 4HS surveys - mapping the Universe

- Preparind a redshift survey - 4MOST example
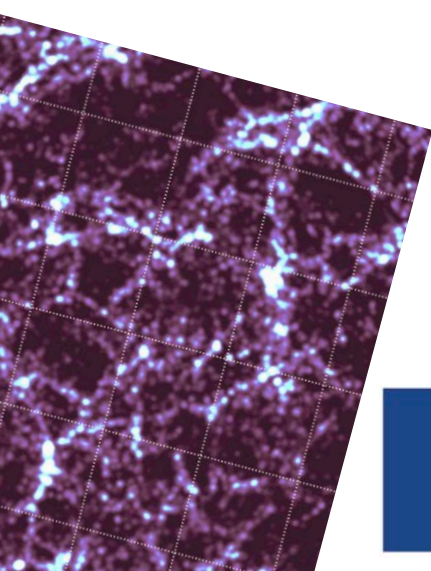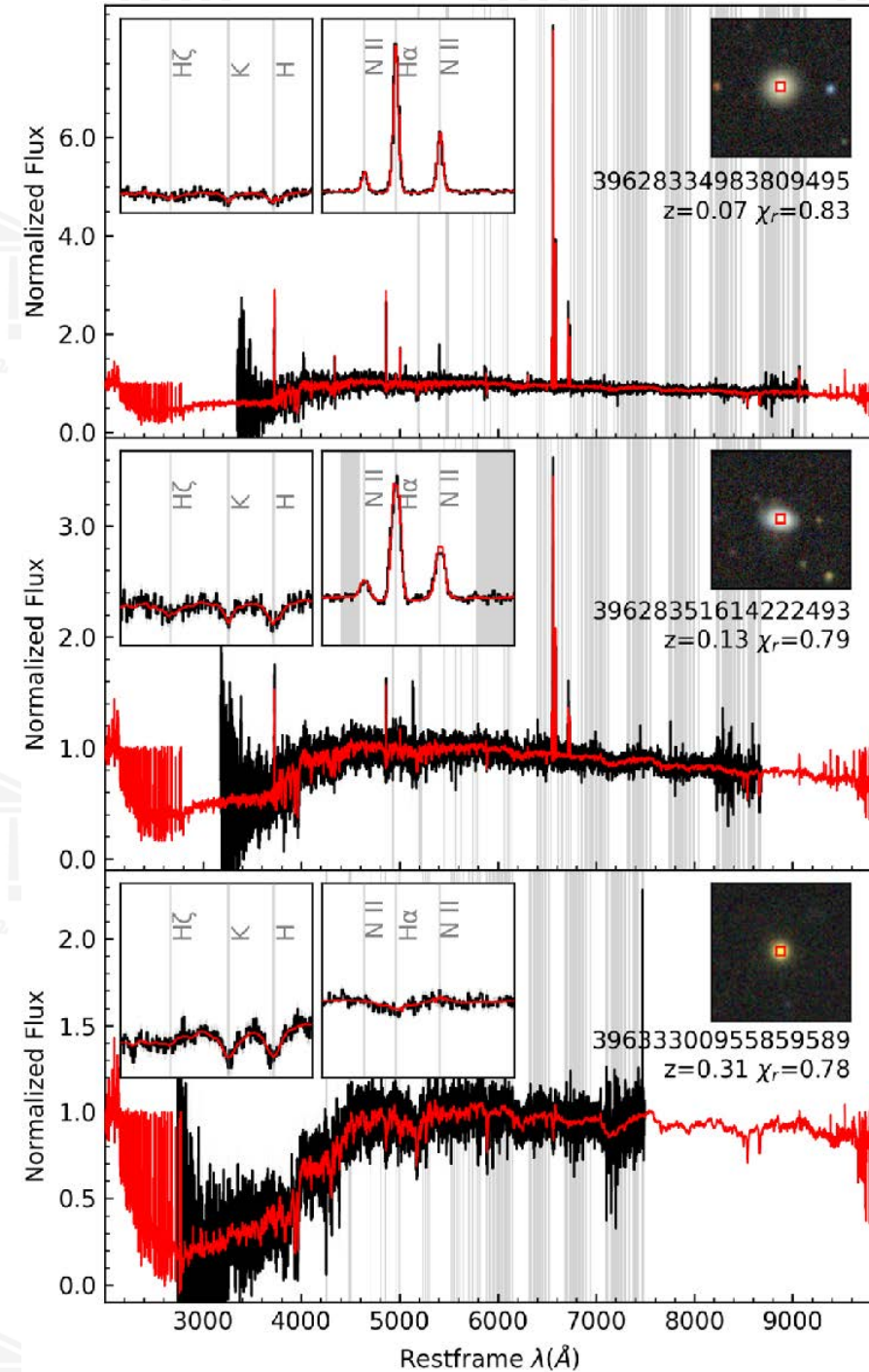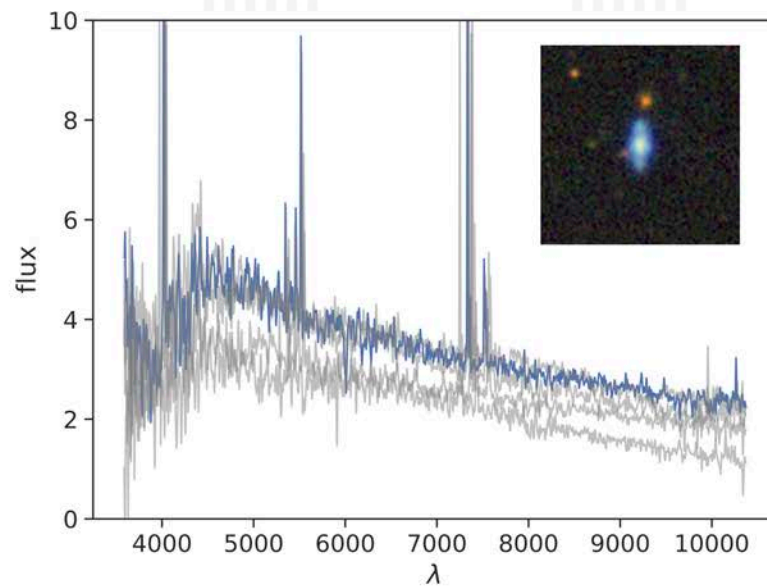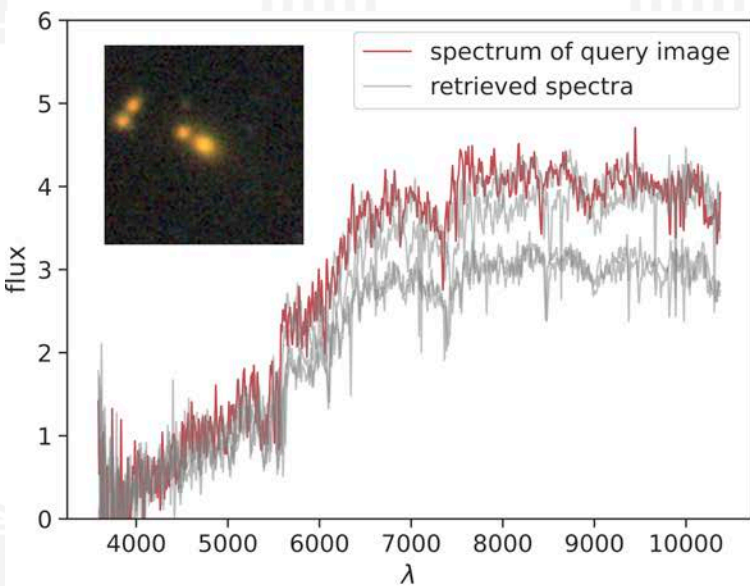

- Understand your data: observational selection effects

- Galaxy Groups in redshift surveys

- Filaments in the Cosmic Web
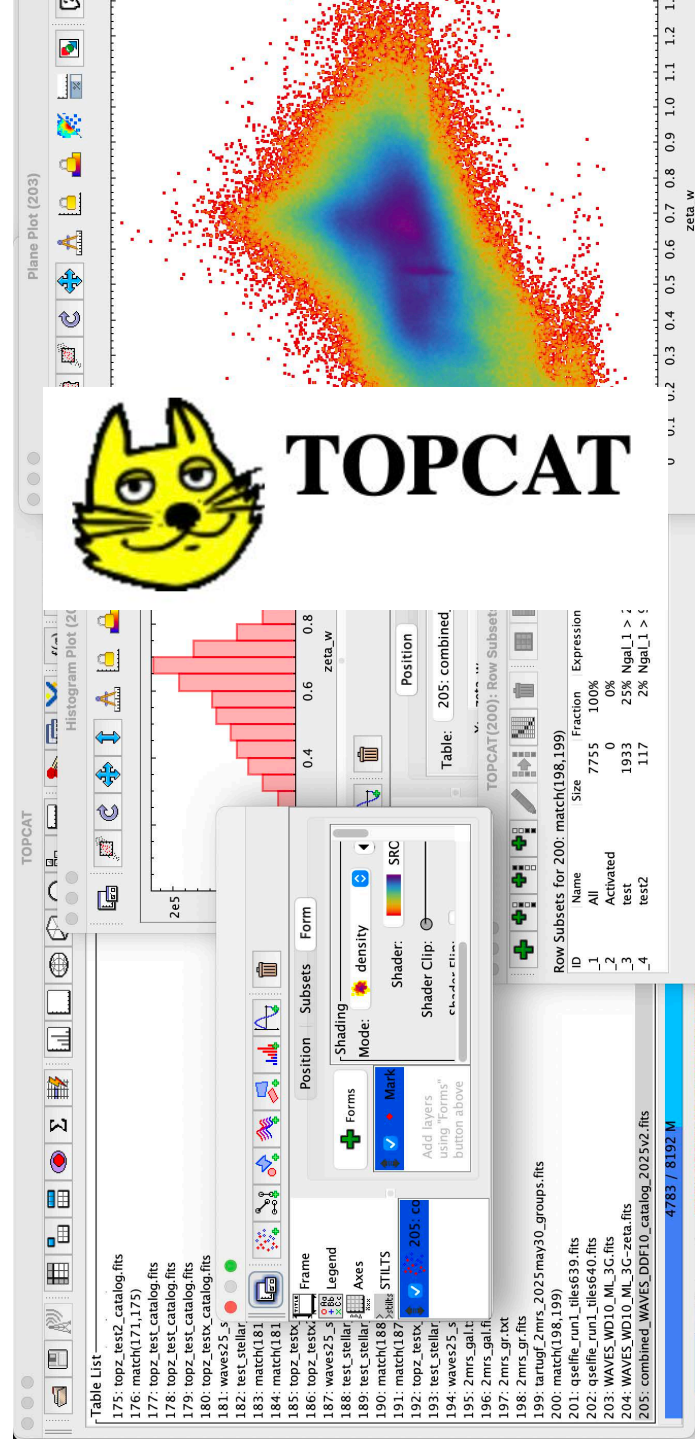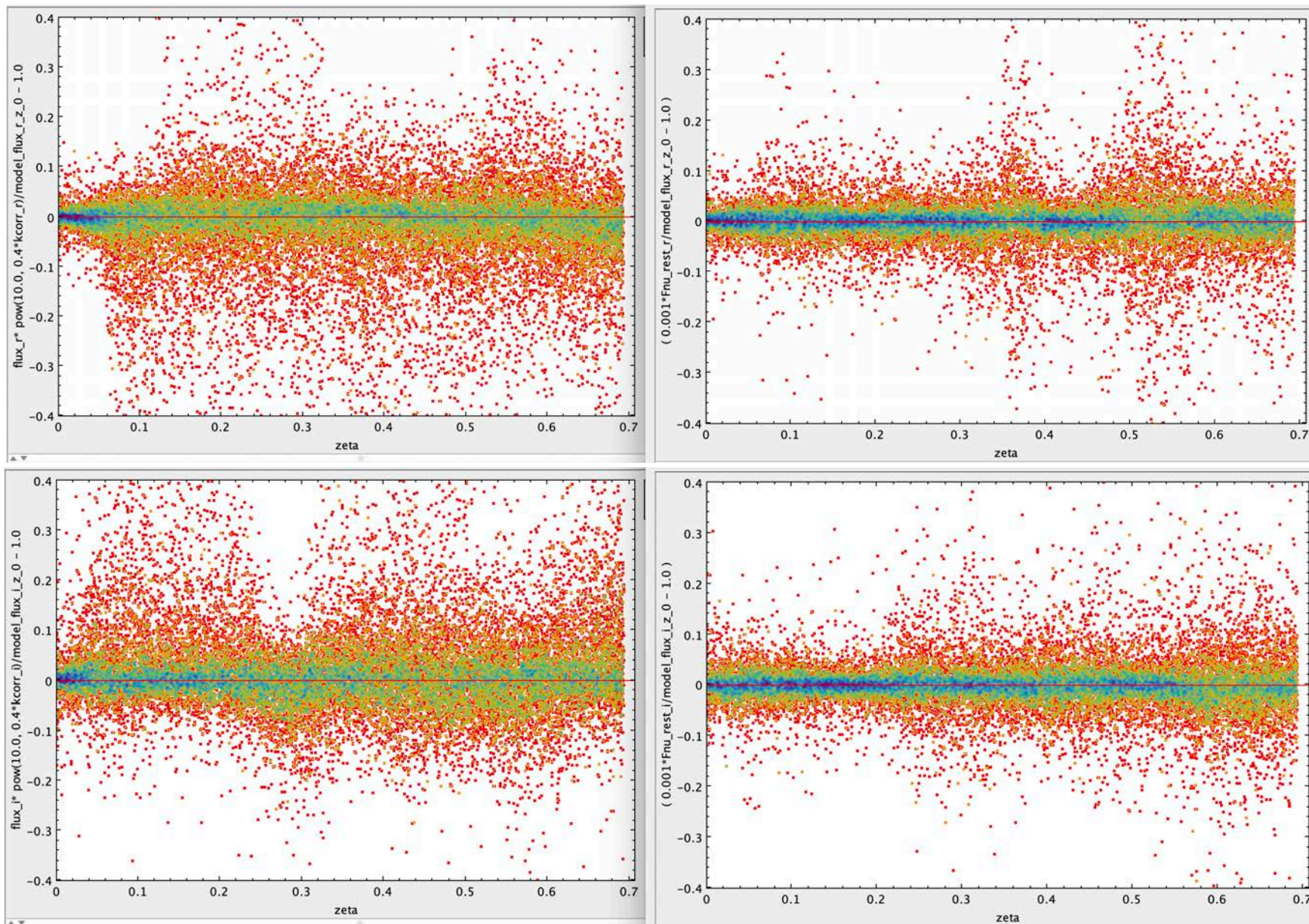
- Selected science topics in Tartu Observatory

Galaxy spectra

Blanton et al.

TOPz k-corrections
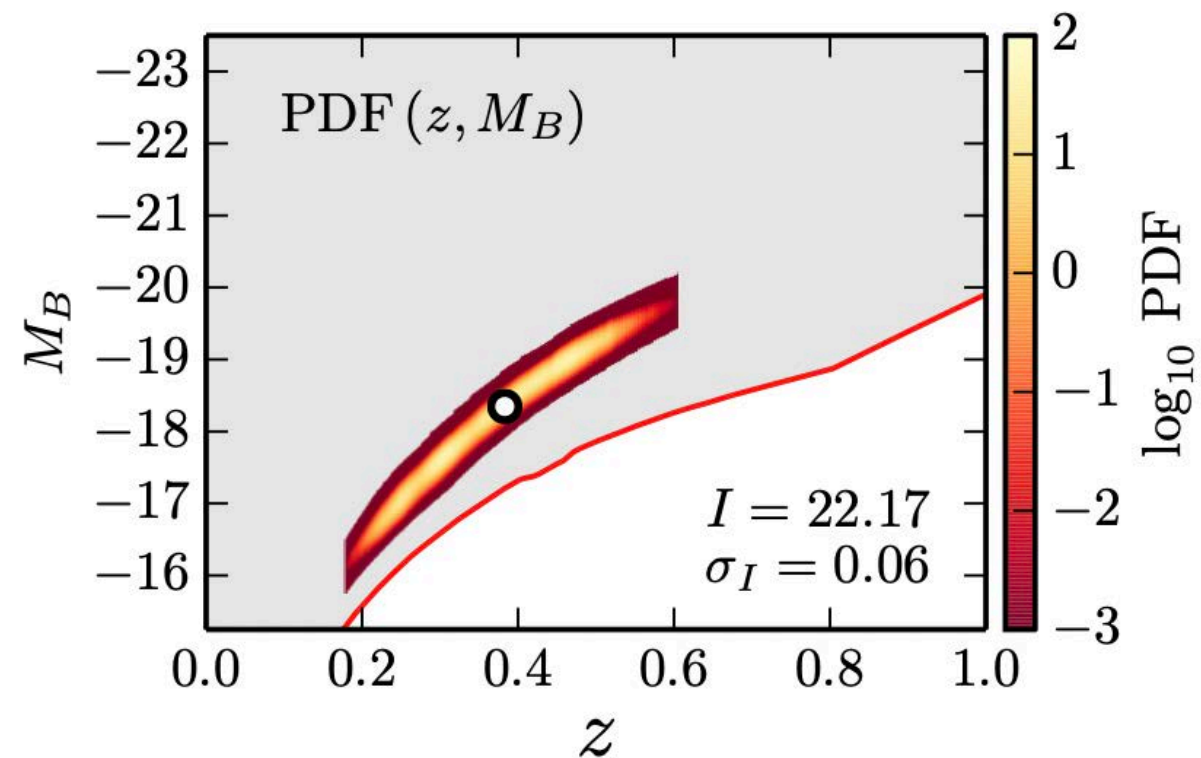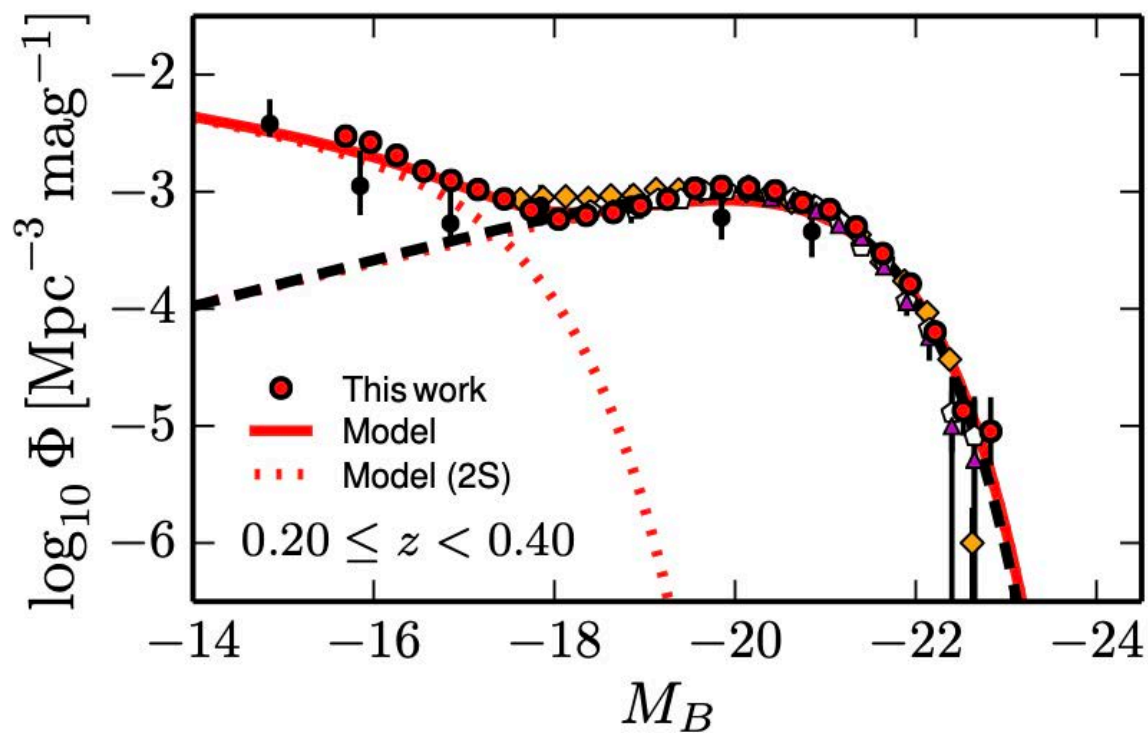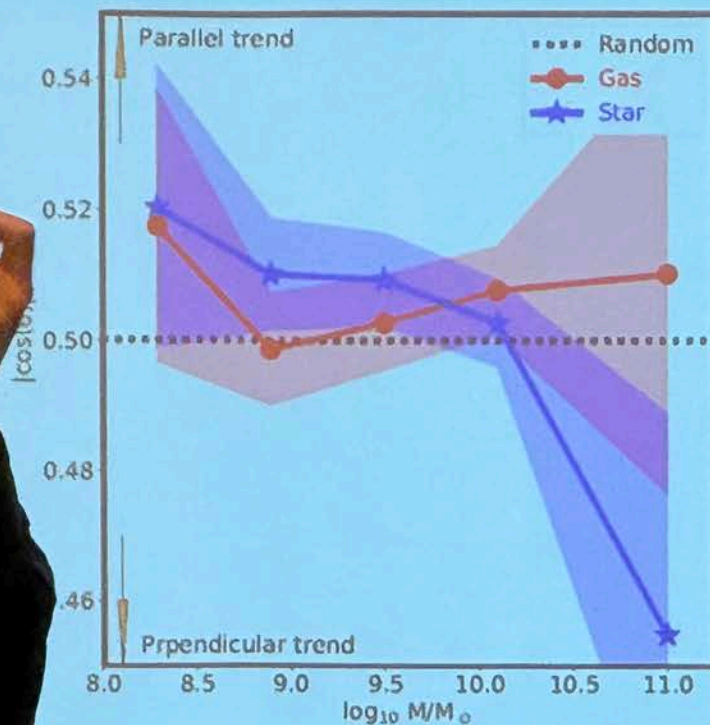
Redshift uncertainty

No one trusts simulations,
except the person who made them!
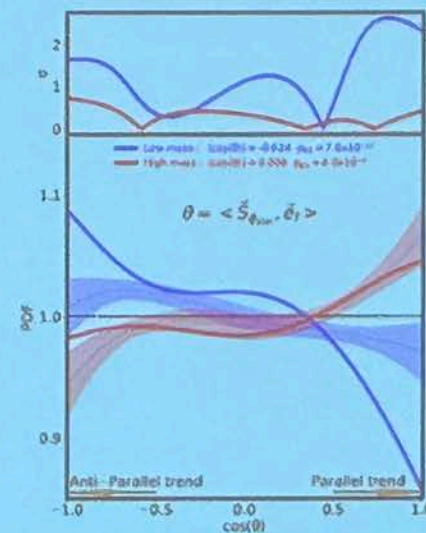

Everyone trusts observations,
except the person who collected the data!
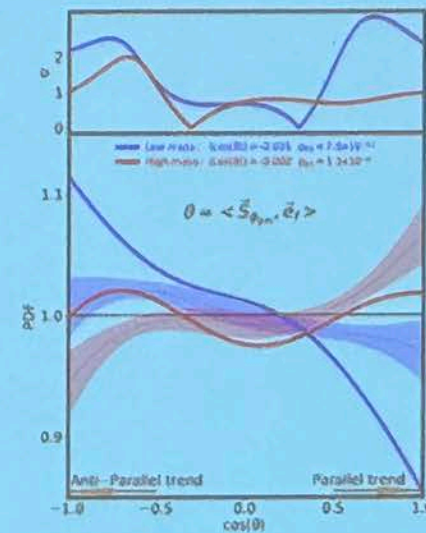
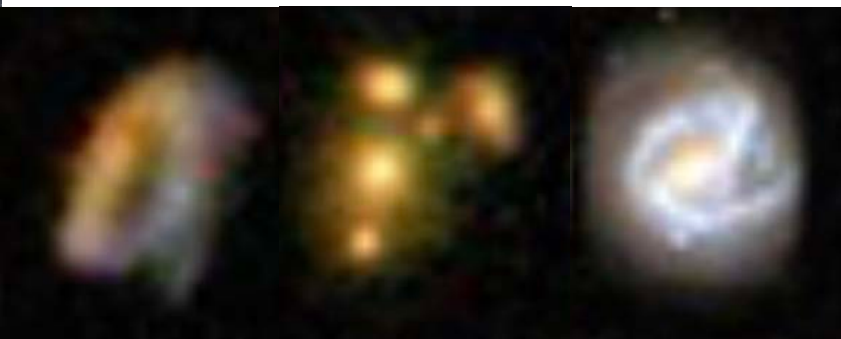Spinning Filaments – Spinning Gals: parallel vs. anti-parallel ?

Wang et al. 2025

Sample MaNGA galaxies (IFU)

Masking stars, ghosts, artefacts

Star-galaxy separation

Baseline Label
- Galaxy
- Star
- Ambiguous

Spectroscopic redshift vs probability z_photo< 0.2
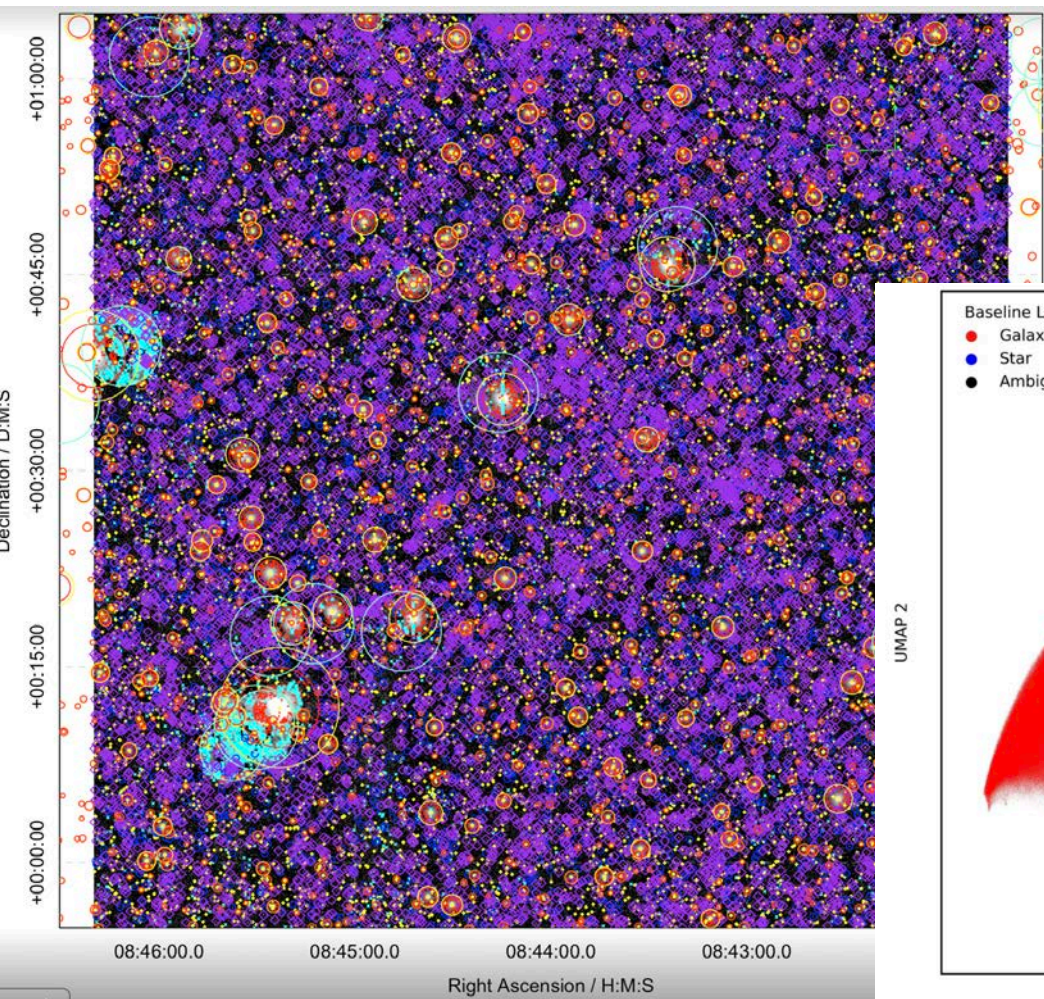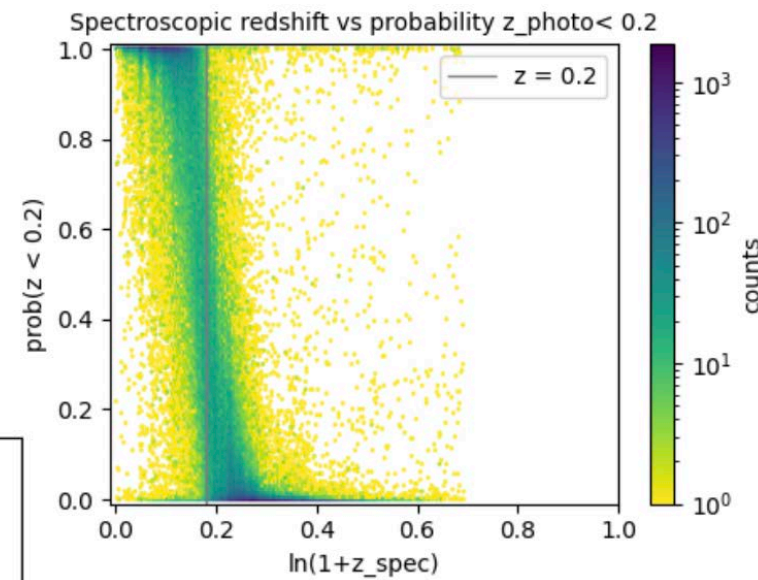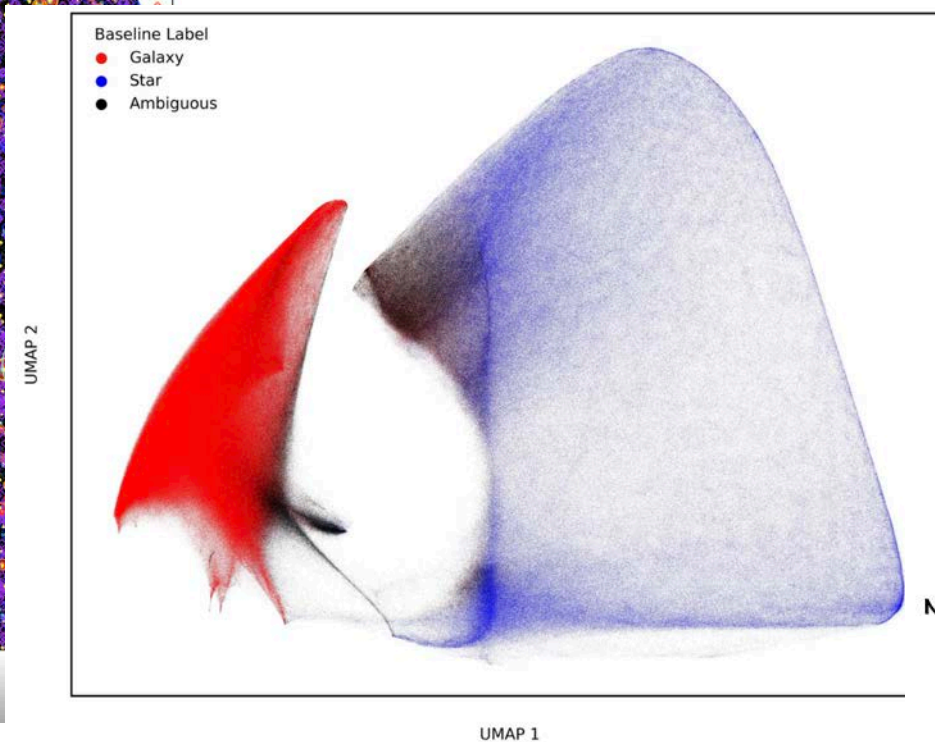
Photo-z preselection
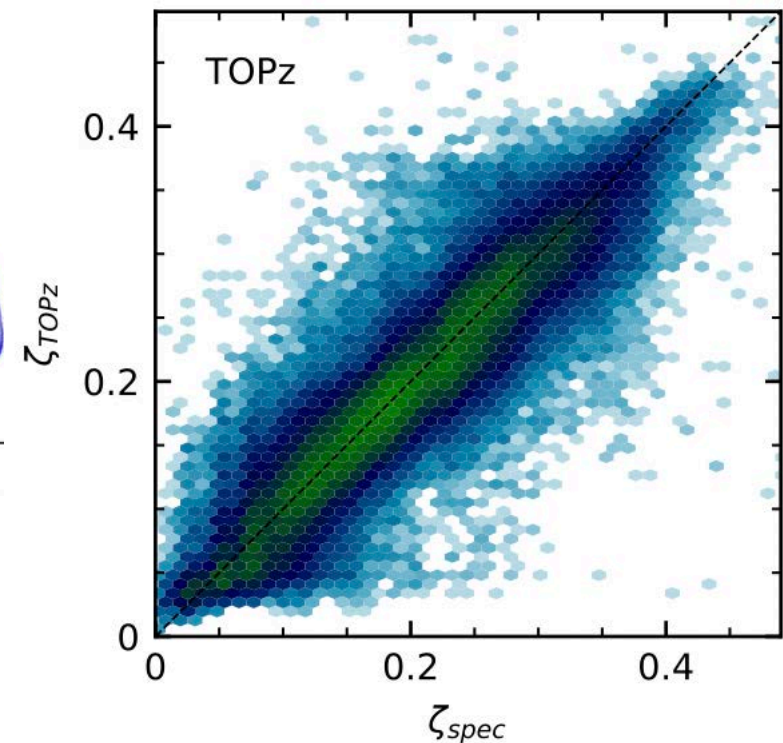
4MOST WAVES survey - target catalogue preparation

Mean ProbSF: 0.86

Fixed fibre pattern

Limited patrol area for each fibre
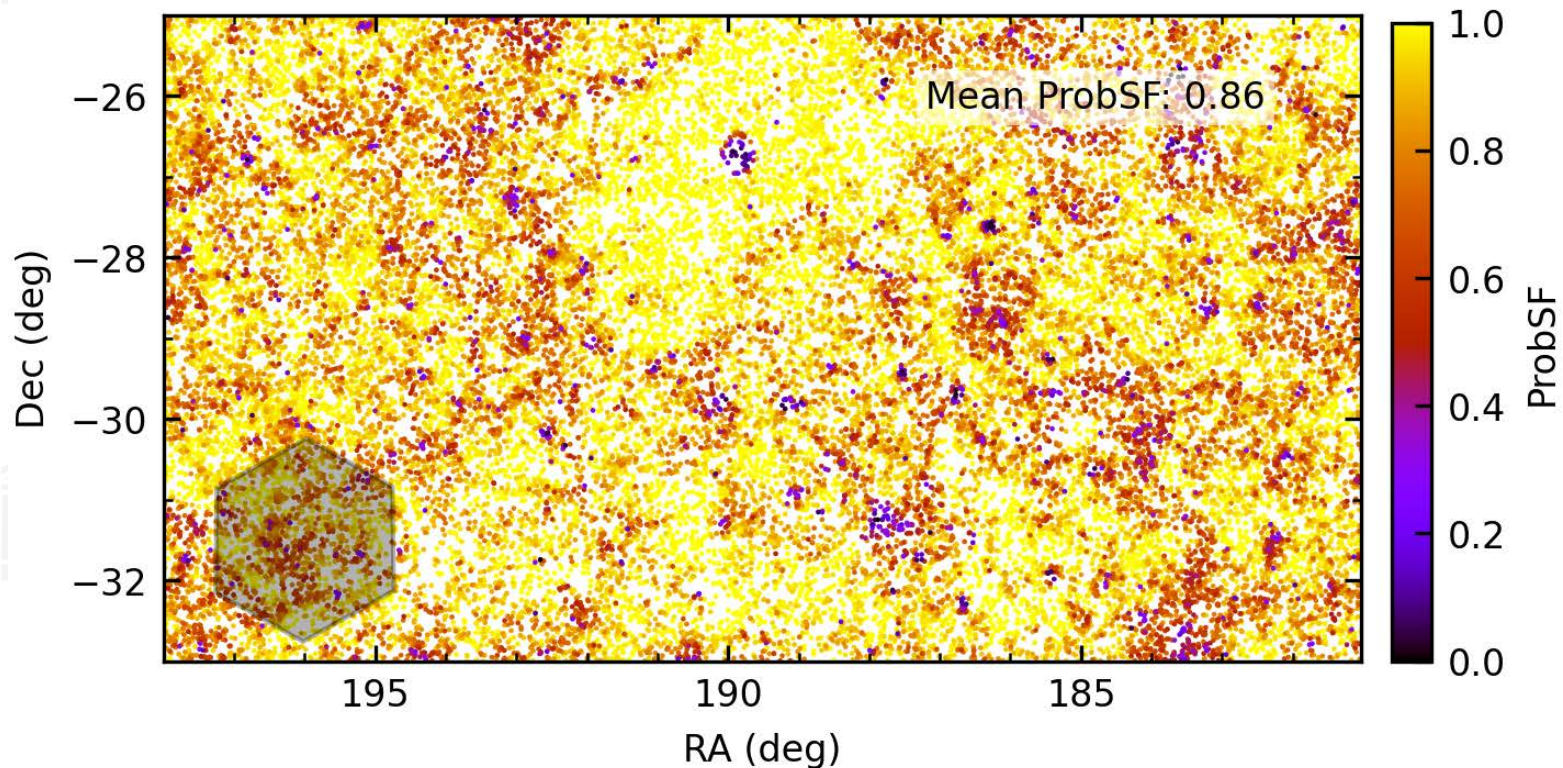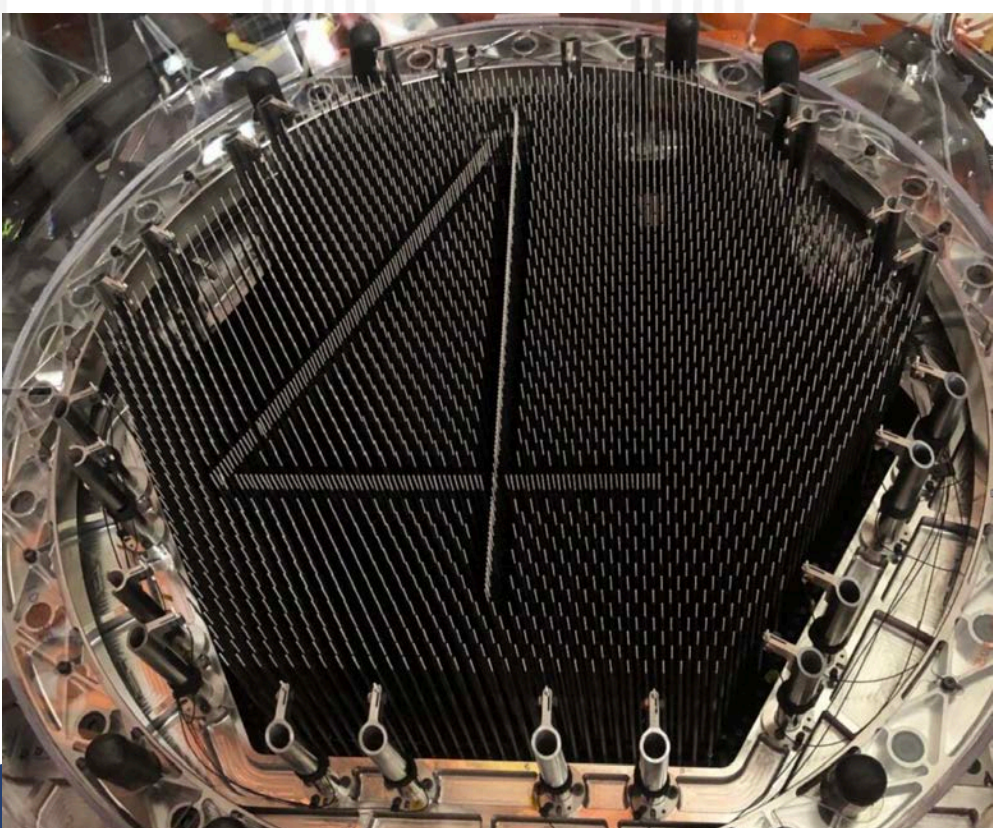
Efficiency   vs   completeness

- all fibres are used
- not all targets are observed

- all targets are observed
- many fibres are empty

Incompleteness in High-Density Areas

4MOST selection function
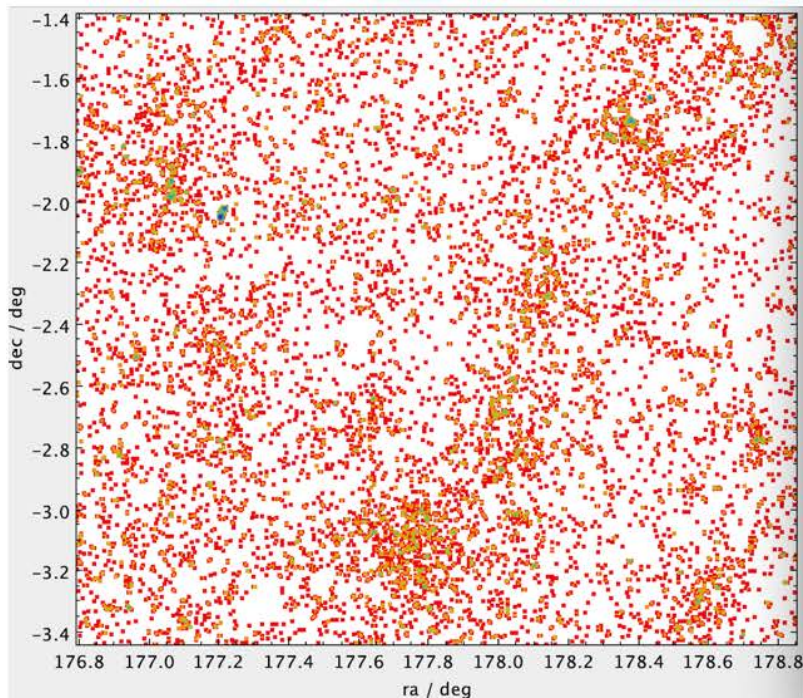
Original catalogue   Observed galaxies   Unobserved galaxies
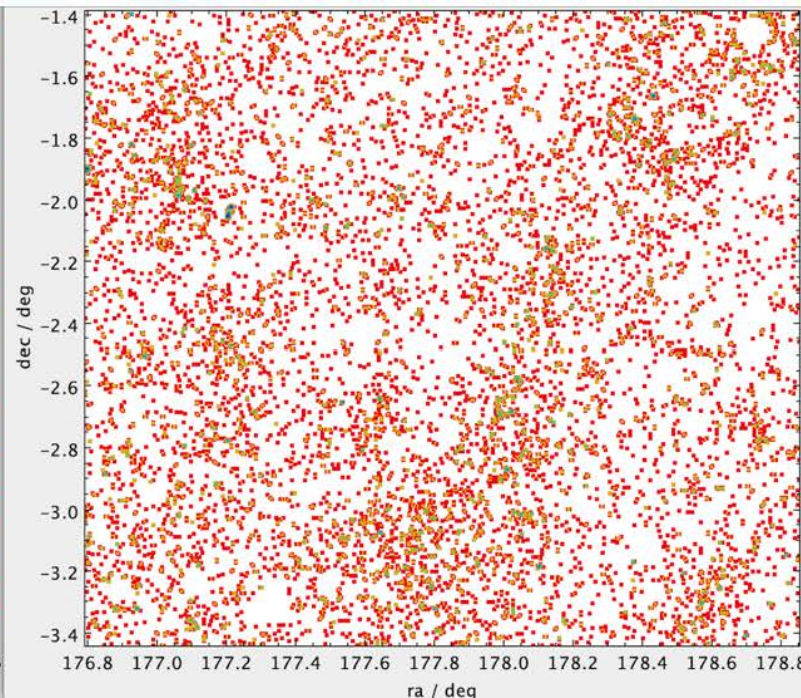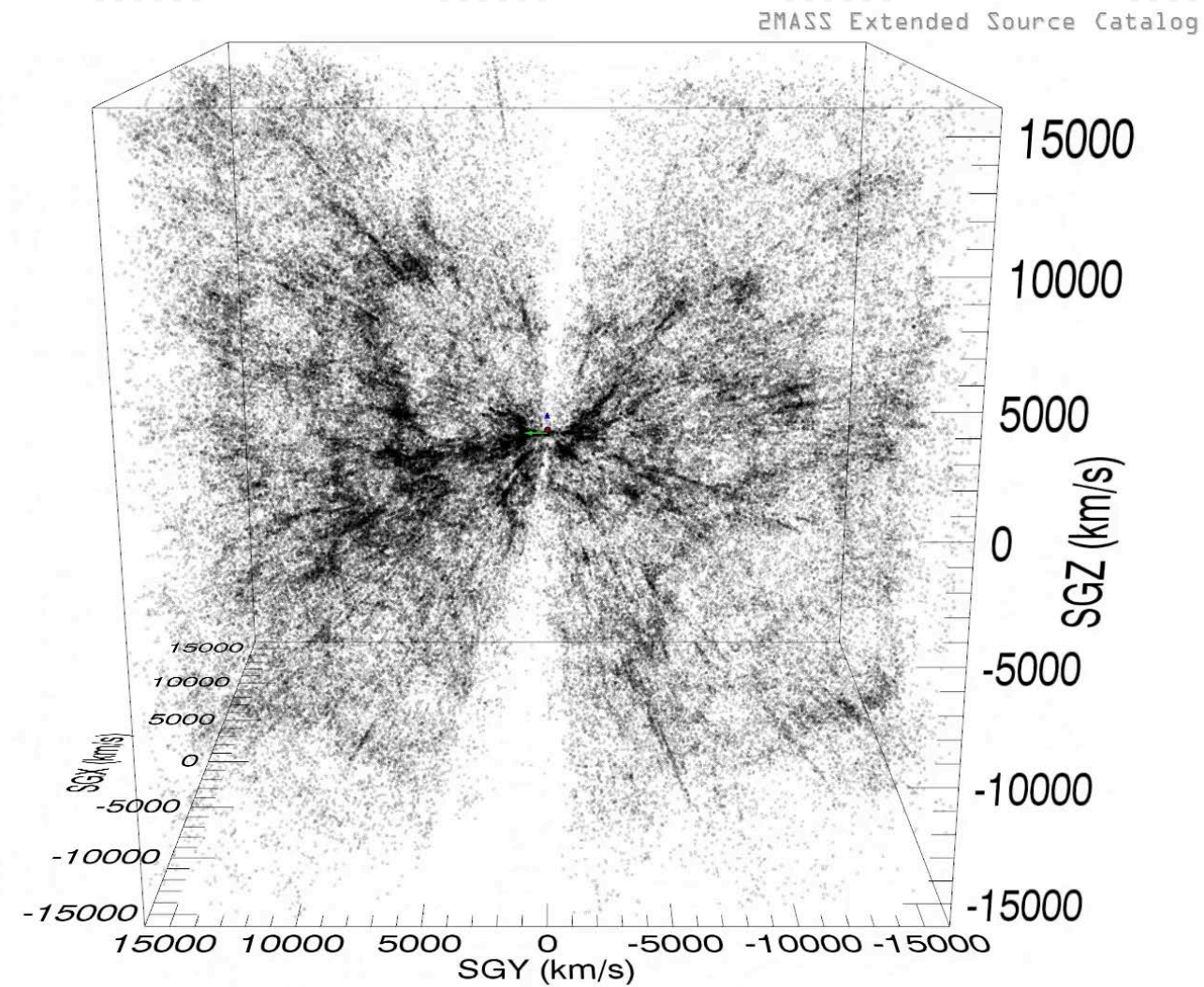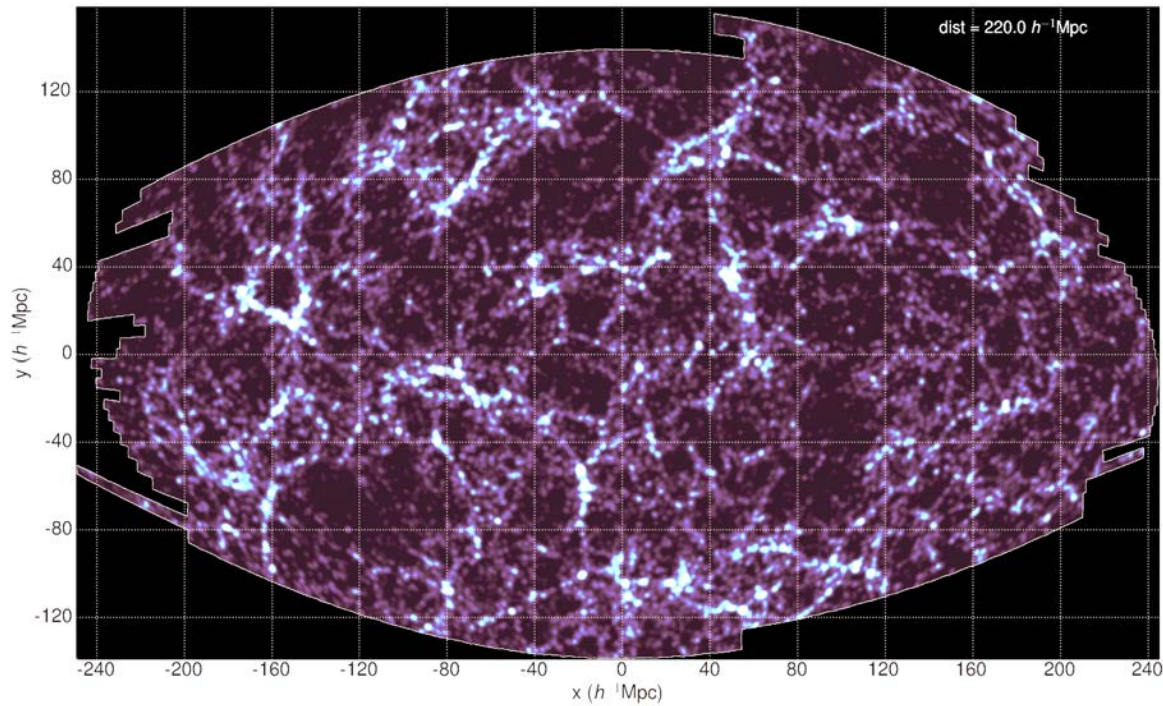
dist = 220.0 h^{-1}Mpc

2MASS Extended Source Catalog

Fingers of god effect

Credit: Tully et al. 2014

Tully & Fisher (1978), IAU Symposium 79,
Large Scale Structures in the Universe,
Tallinn, 1977
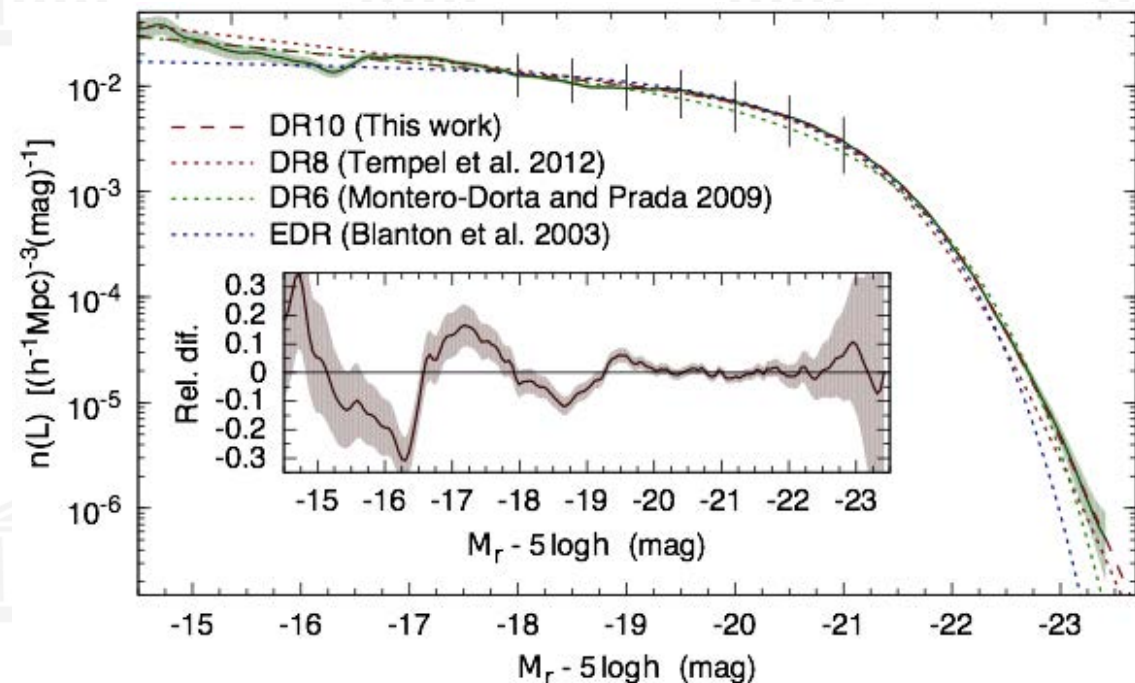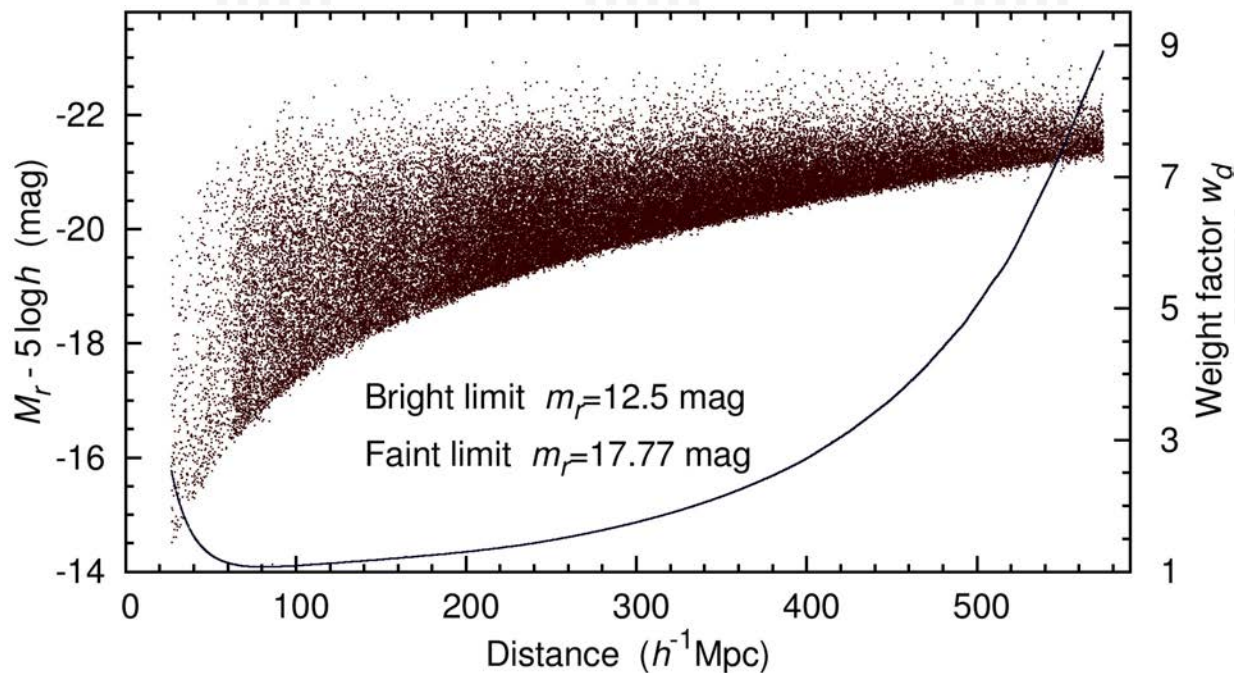
ET et al. 2012, 2014

Flux-limited survey effect

Fainter galaxies are missing
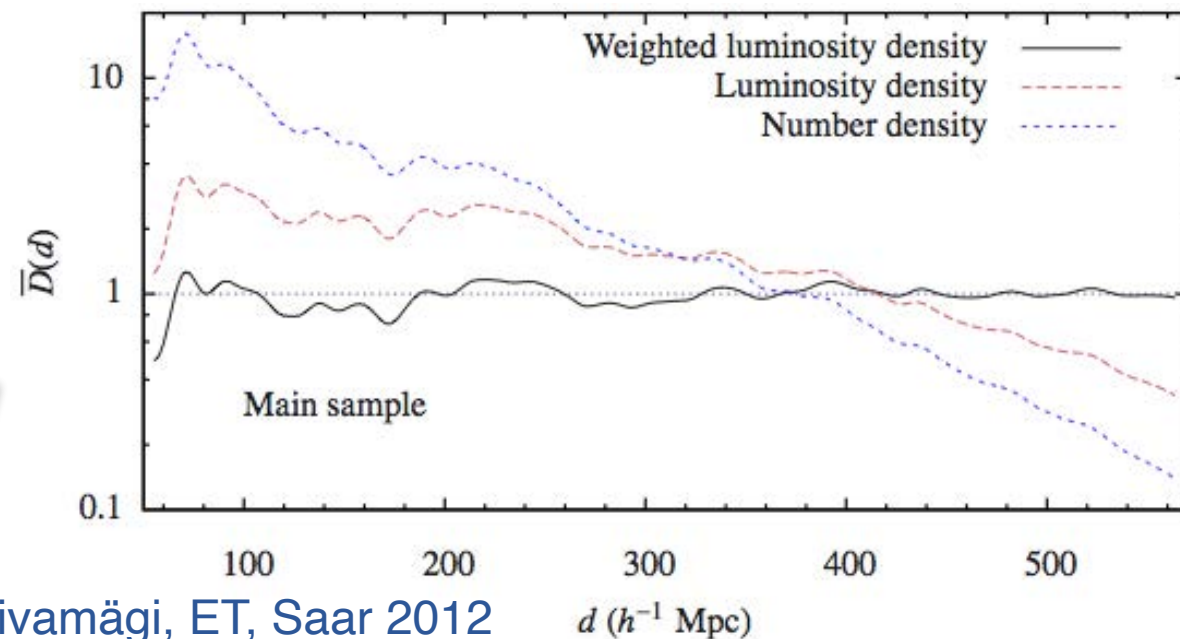
Liivamägi, ET, Saar 2012

Observations: selection effects

2MASS Extended Source Catalog Redshift Survey
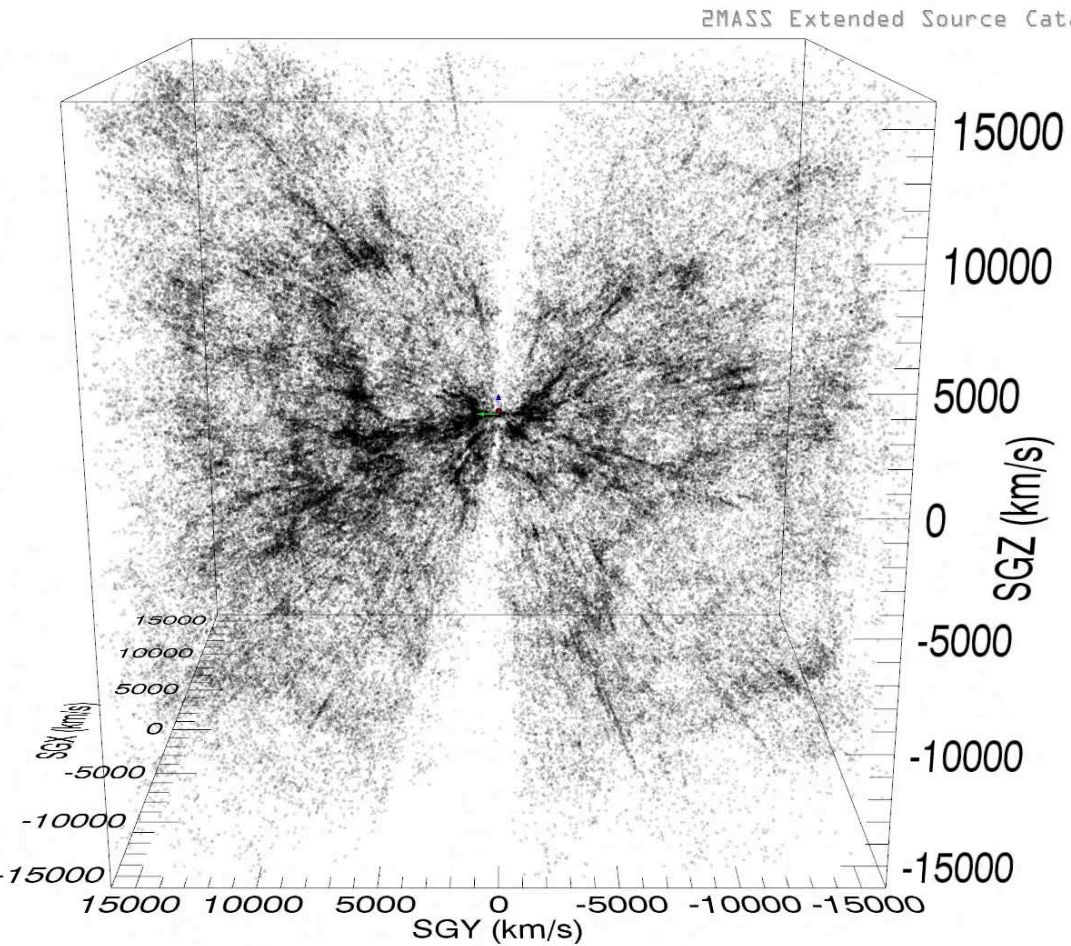
Courtesy: Tully et al. 2014

Fingers-of-god effect:
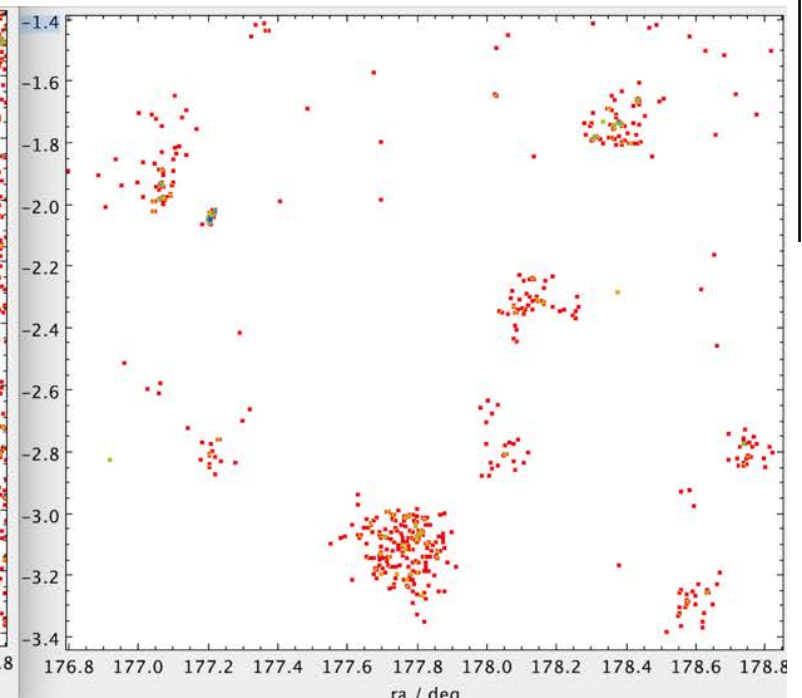Tully & Fisher (1978), IAU Symposium 79, Large Scale Structures in the Universe, Tallinn, 1977

Detecting galaxy groups and clusters:
- Friends of friends
- Marked point processes
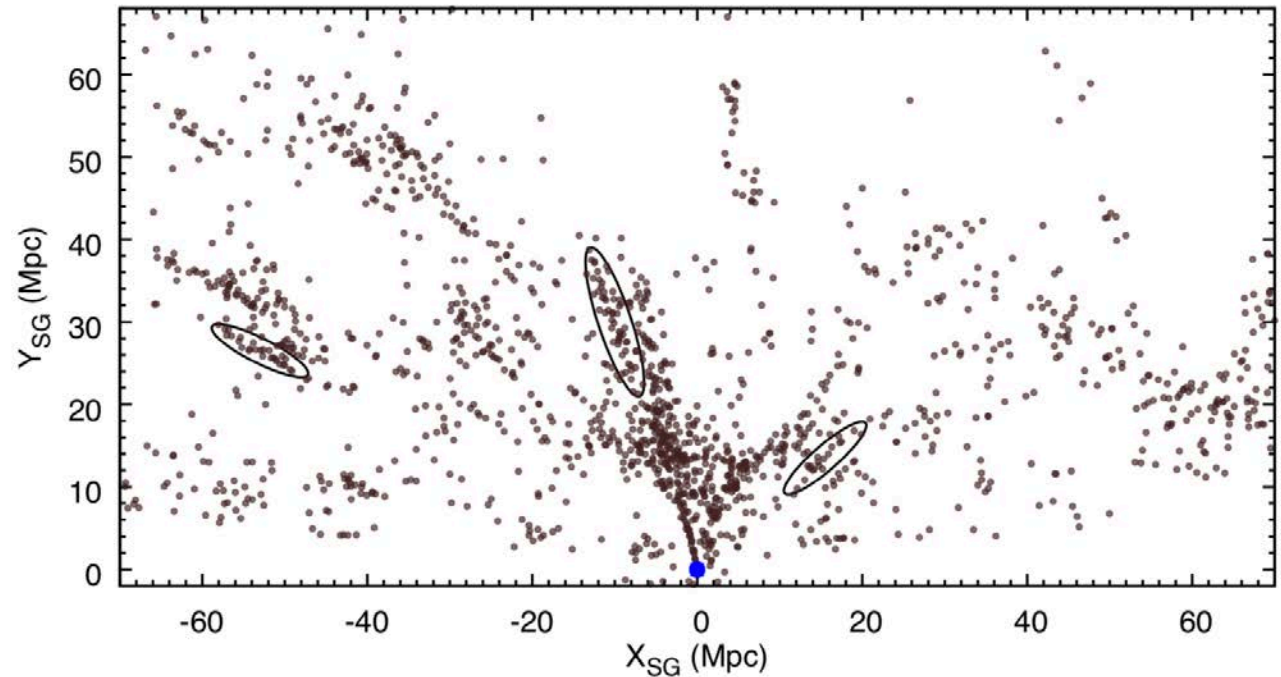
Tempel et al. (2012, 2014, 2017, 2018) 119

Observations: selection effects
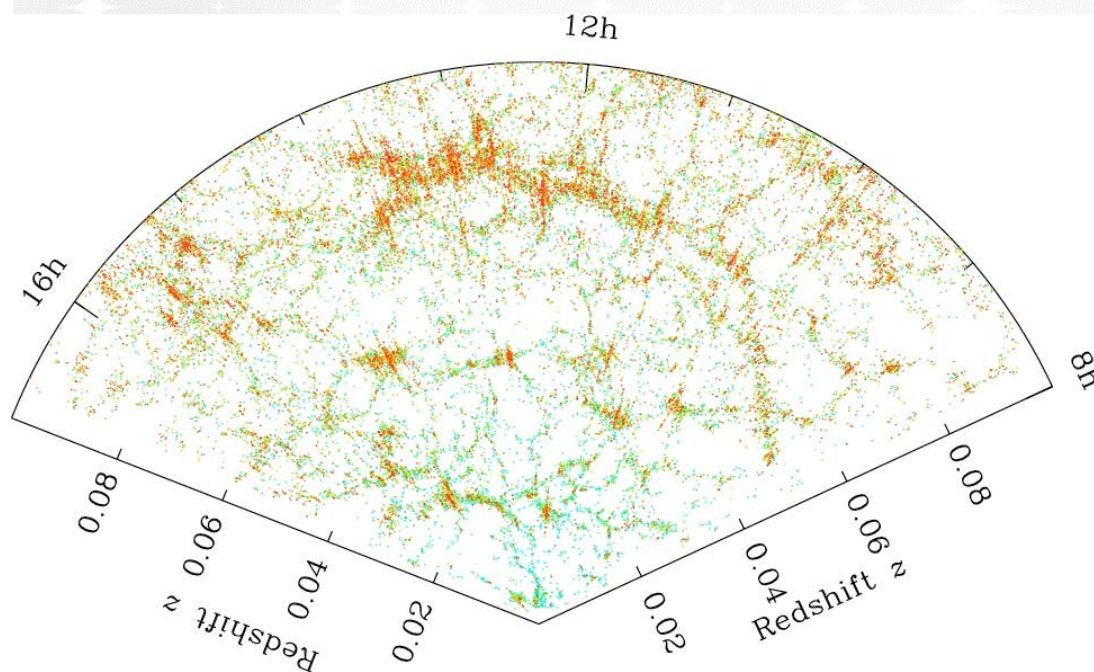
Finger-of-god effect:

Tully & Fisher (1978), IAU Symposium 79,
Large Scale Structures in the Universe,
Tallinn, September 12-16, 1977
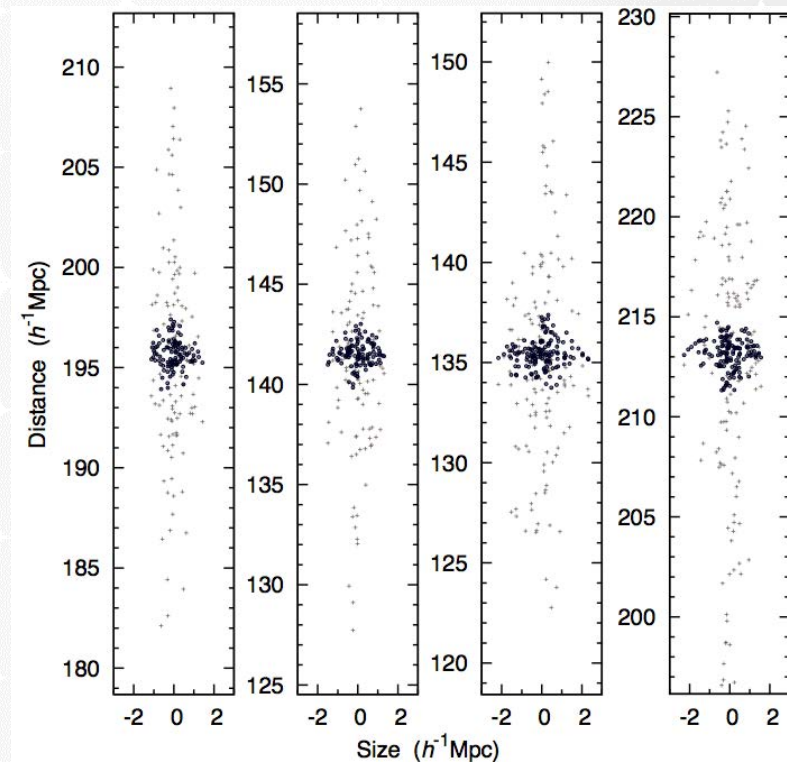
Tempel et al. (2012)

Using friends-of-friends galaxy groups,

we suppress the finger-of-god distortions.

Observed: with FoG effect

Corrected: without FoG effect
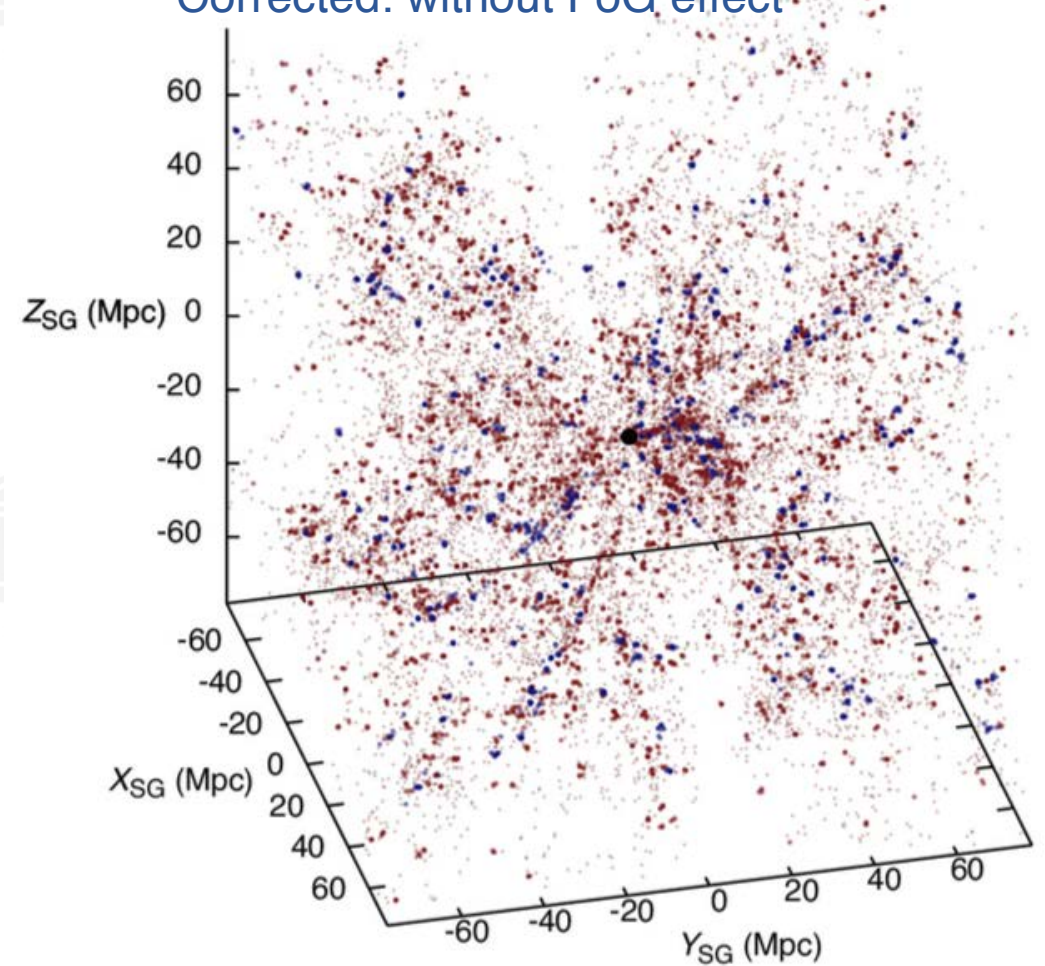
Fingers of god effect

Using galaxy groups to spherise groups

Detecting groups in redshift surveys:
ET et al. 2012, 2014, 2016, 2017, 2018

Luminosity function of galaxies

Fig. 13. Differential LFs for various galaxy populations: first-ranked, satellite, first-ranked+satellite (group), first-ranked+isolated, isolated and all galaxies. The points are LFs, using 2dF galaxy catalogue. Error-bars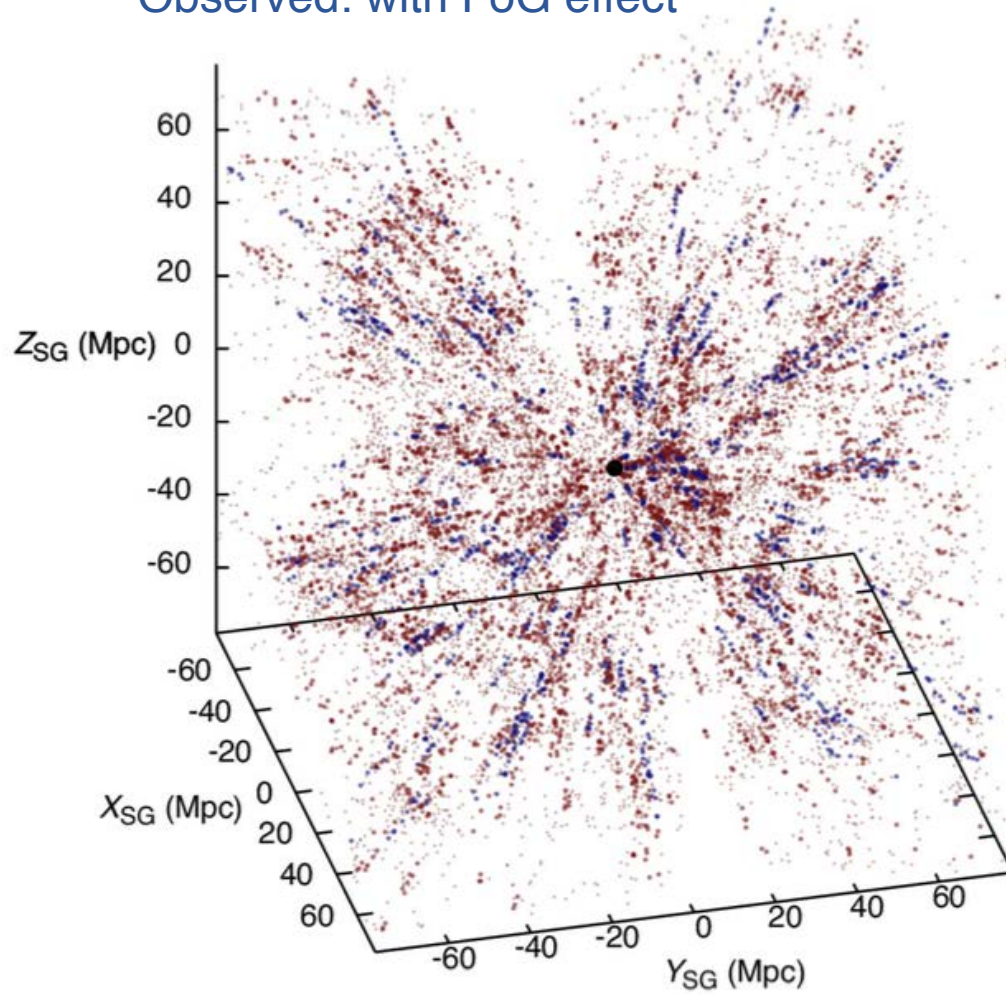 are Poisson 1-σ errors. The red solid line is the double-power law and the green dashed line is the Schechter function.

Luminosity function - new method

Standard $1/V_{max}$ method:

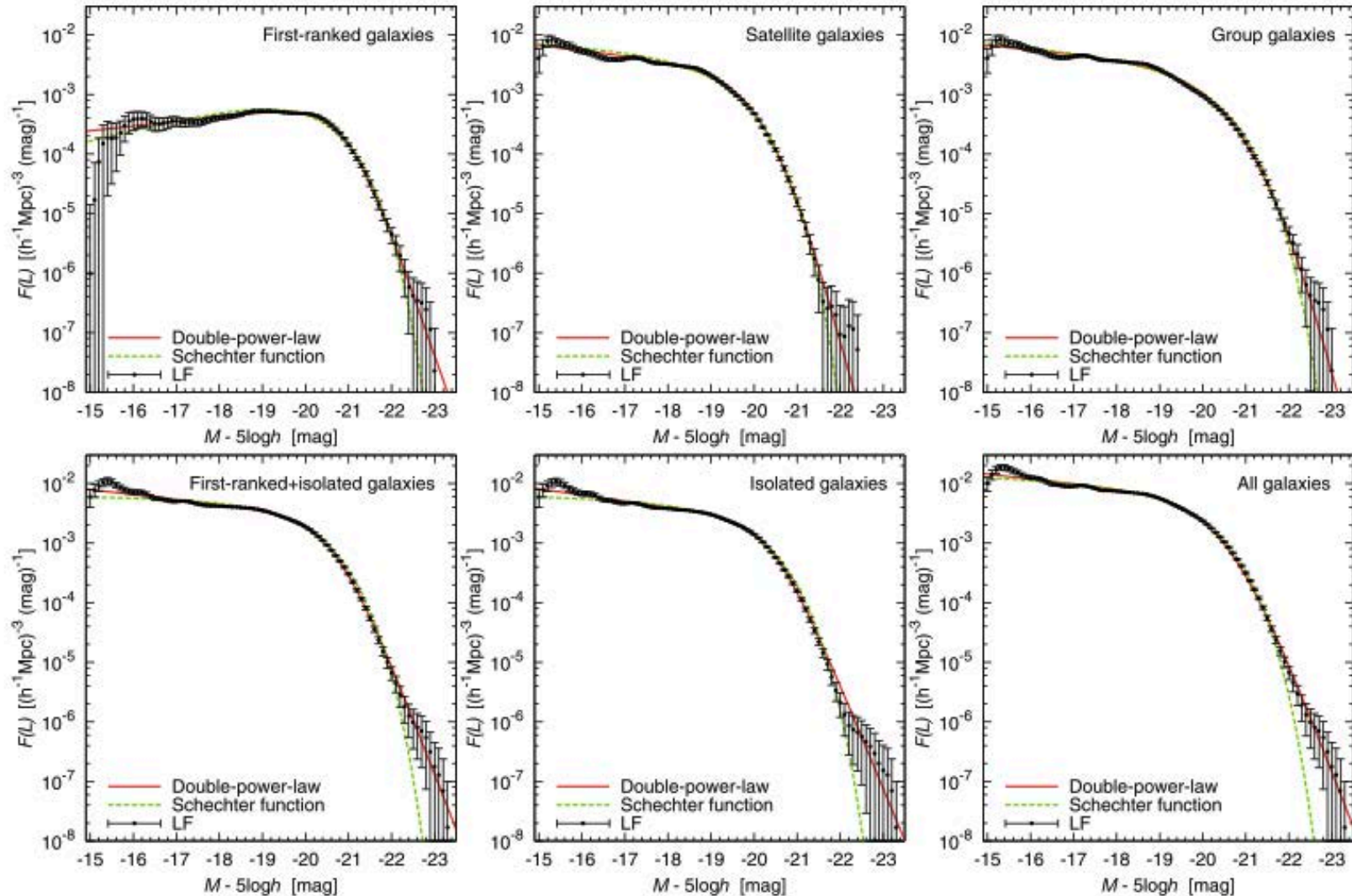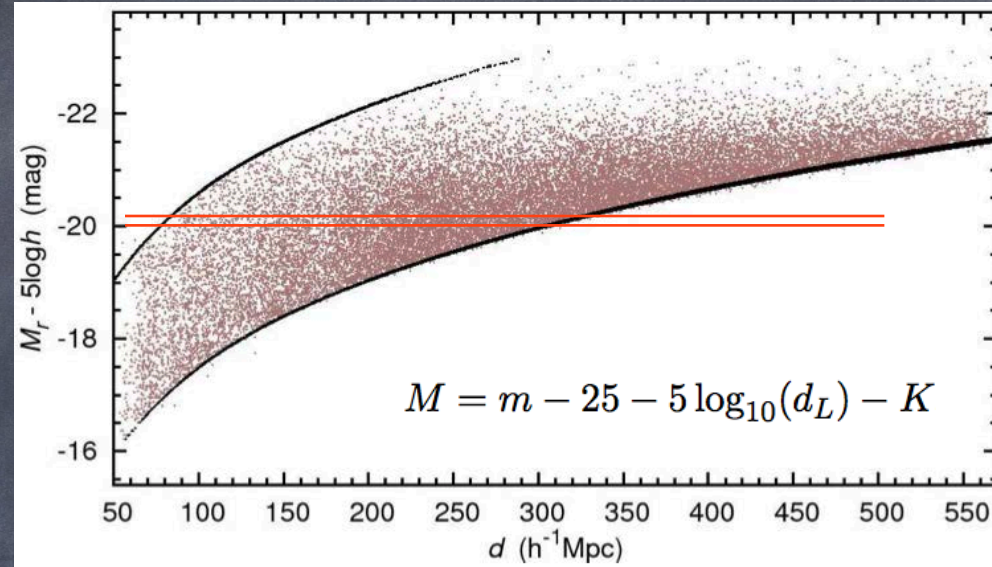$$n(L)dL = \sum_i \frac{\mathbf{I}_{(L,L+dL)}(L_i)}{V_{max}(L_i)}$$
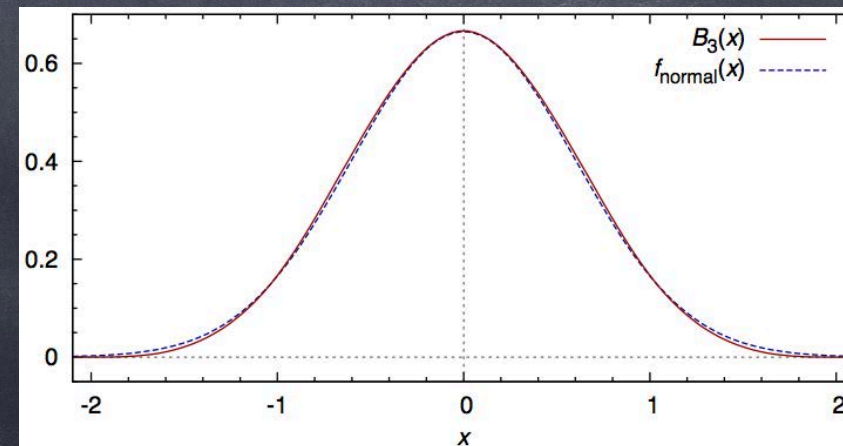
(binned density histogram)

$$M = m - 25 - 5\log_{10}(d_L) - K$$

Sum of kernels centered at the data points:

$$n(L) = \sum_i \frac{1}{V_{max}(L_i)} \frac{1}{a_i} K\left(\frac{L - L_i}{a_i}\right)$$

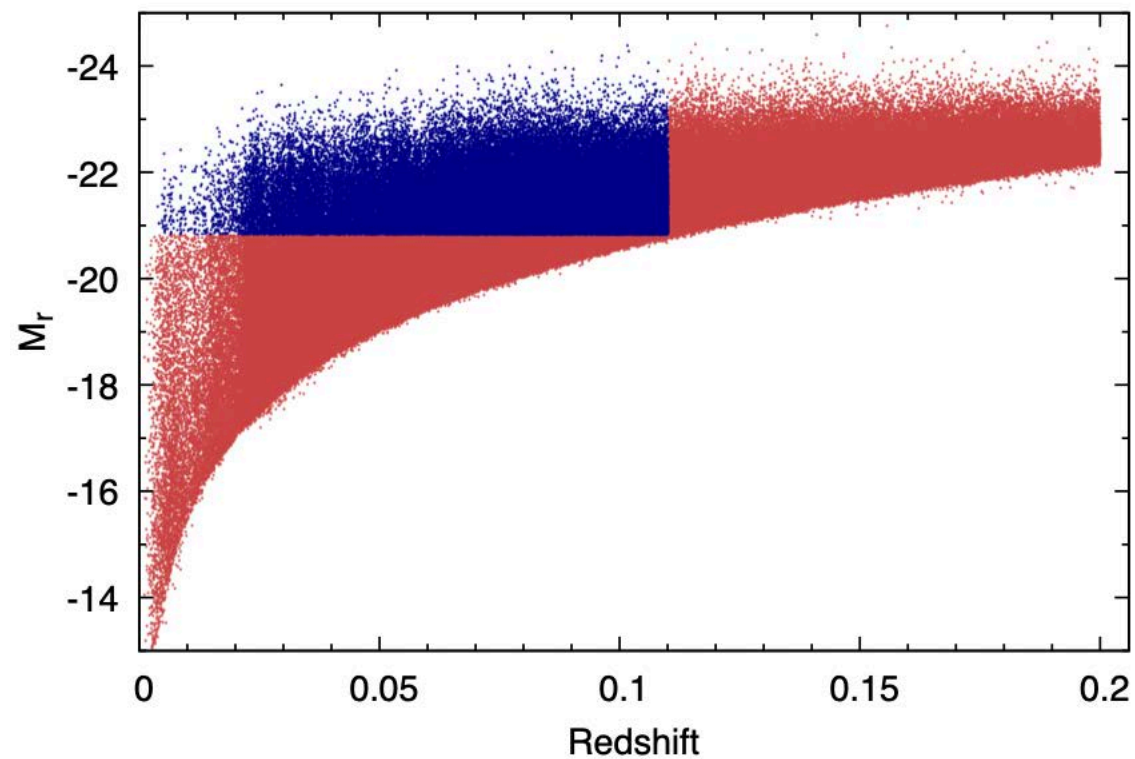(adaptive kernel estimation)

Error bars: smoothed bootstrap
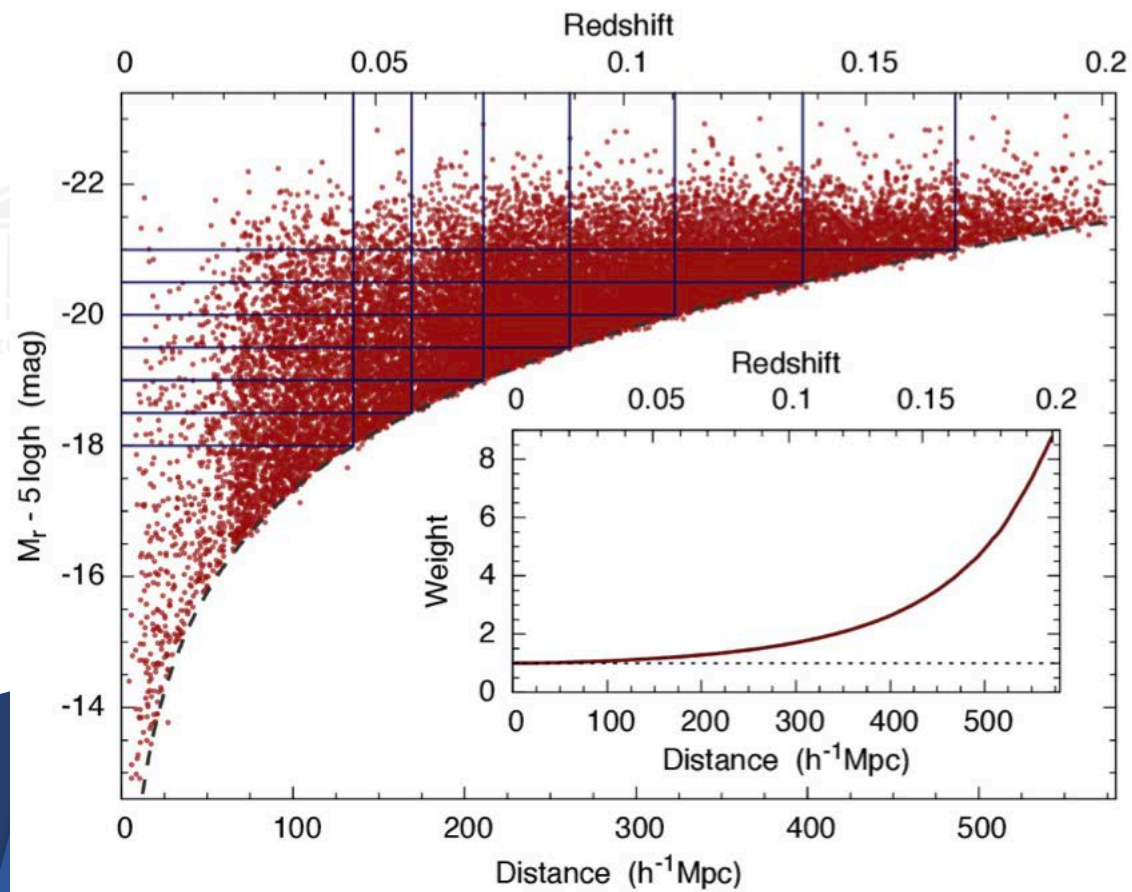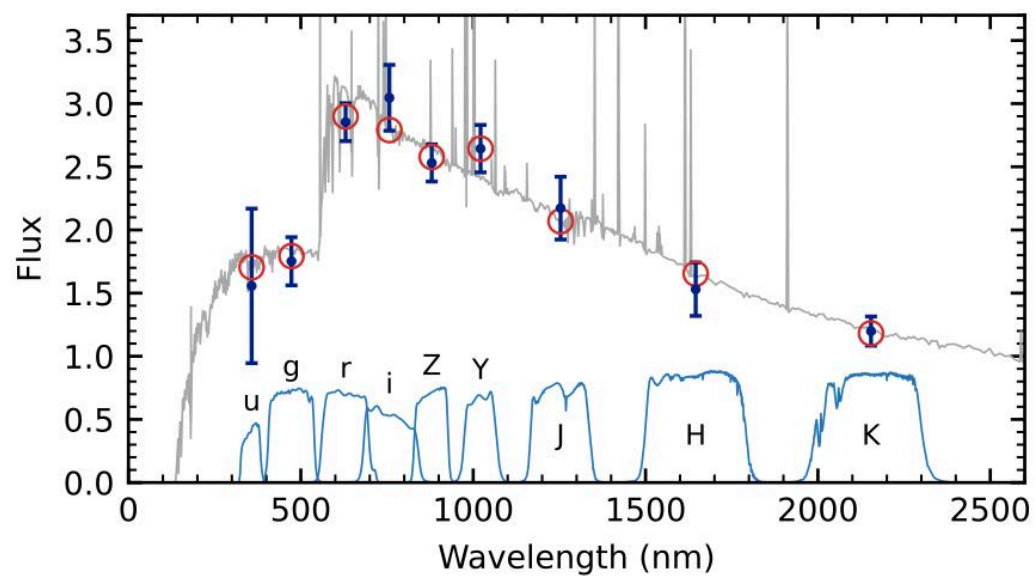
Luminosity function of galaxies

- flux-limited survey
- k-corrections - absolute luminosity
- galaxy dependent limiting distances
- dust effects on luminosity
- inclination angle effects
- surface brightness limitations
- incompleteness in redshift surveys
- redshift to distance conversion (pec vel)

$$M_\lambda = m_\lambda - 25 - 5\log_{10}(d_L) - K,$$

Flux vs volume limited

Galaxy spectra
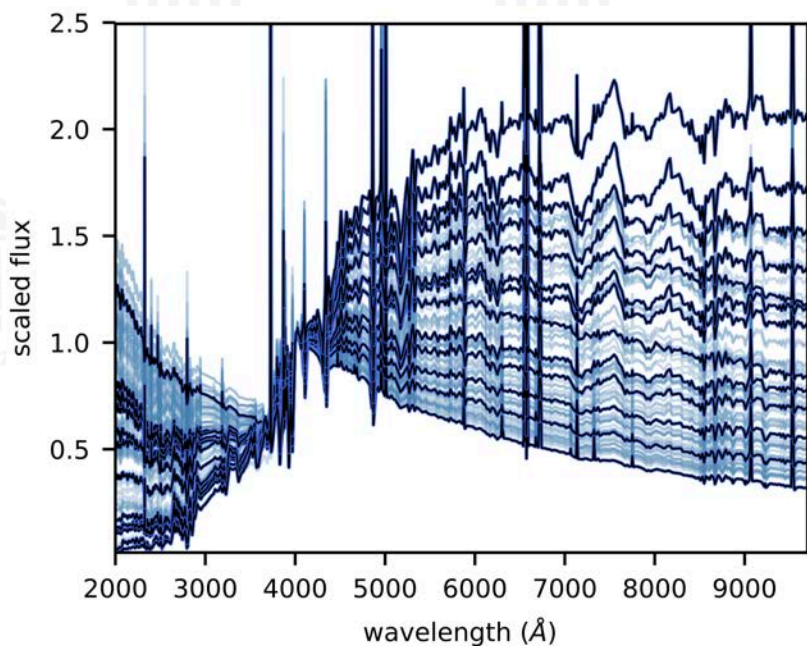
k-corrections

Same galaxy at different redshifts

Elliptical Galaxy at z=0.7

Elliptical Galaxy at z=0.4

Elliptical Galaxy at z=0.0

Galaxy modeling

TARTU OBSERVATORY
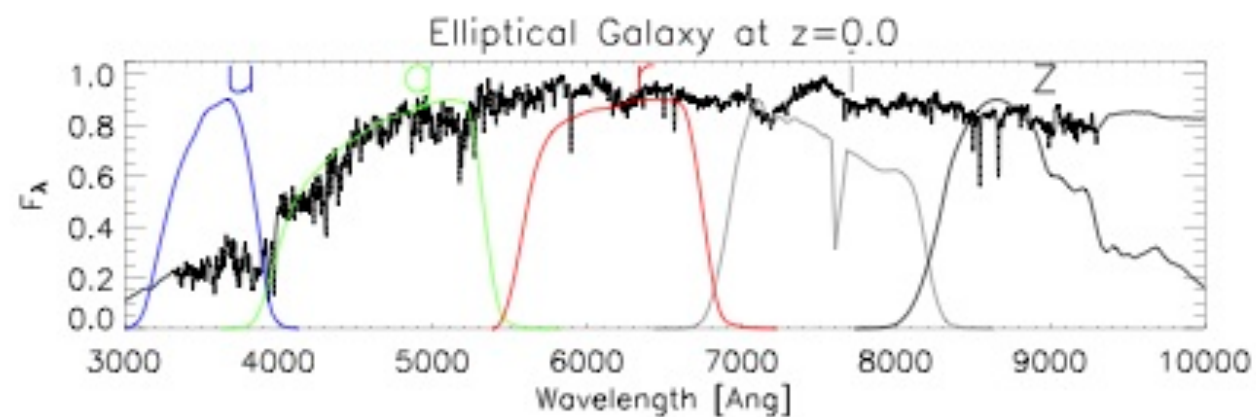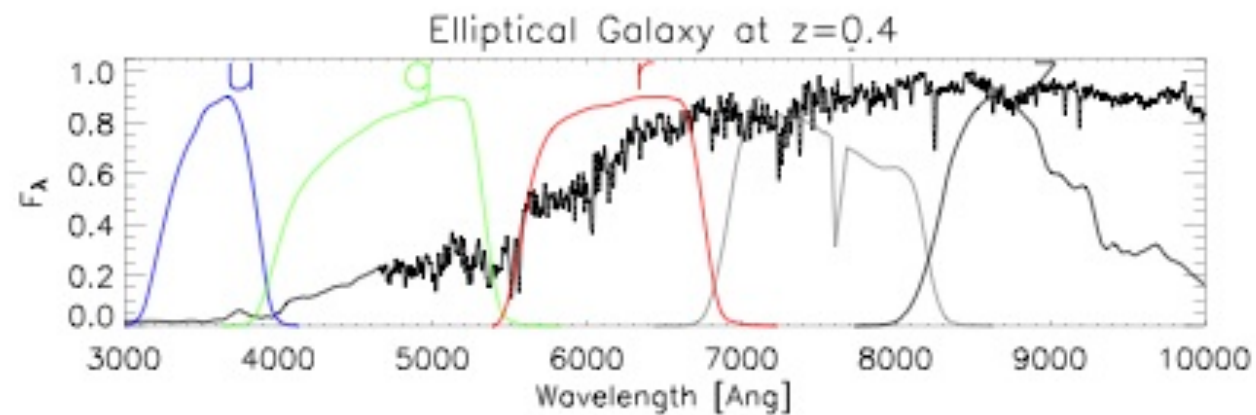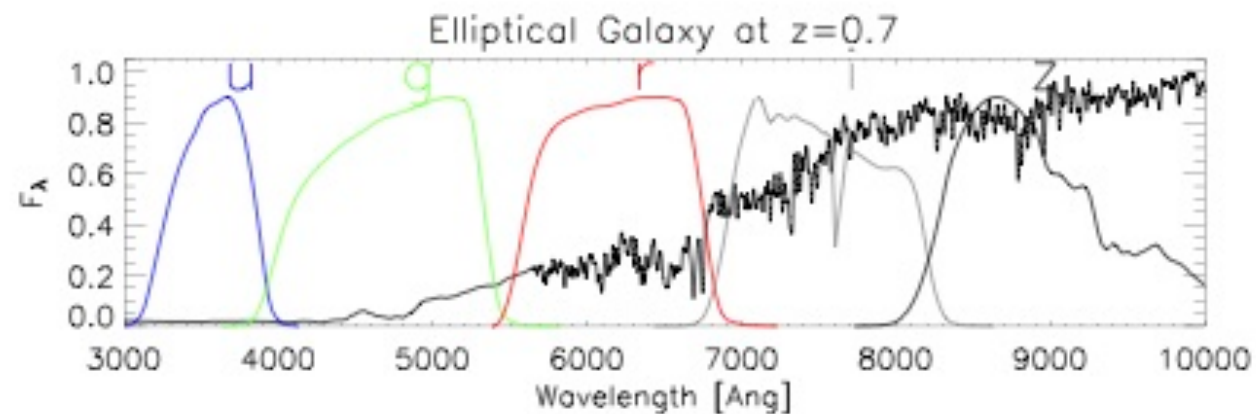space research centre

- Simple bulge+disc model...

- ... add dust disc to improve inclination angle estimation

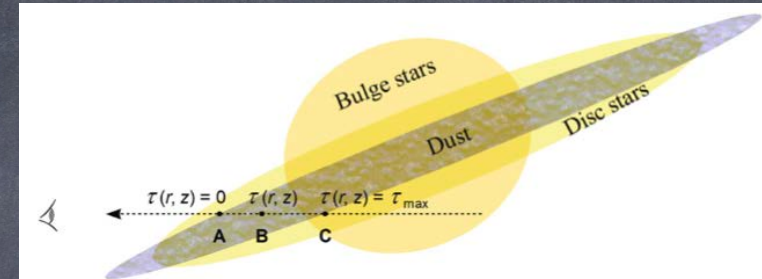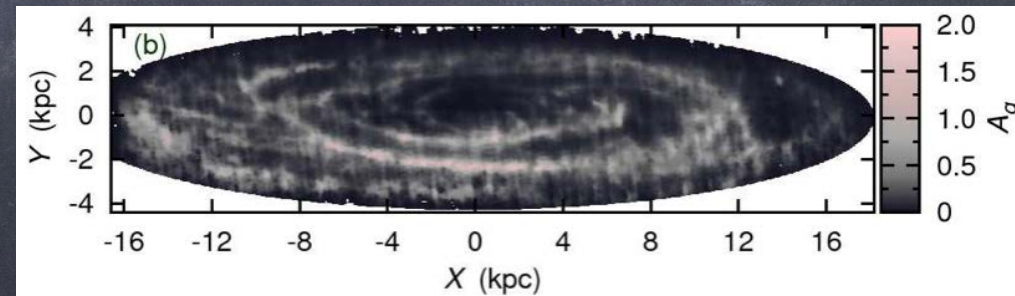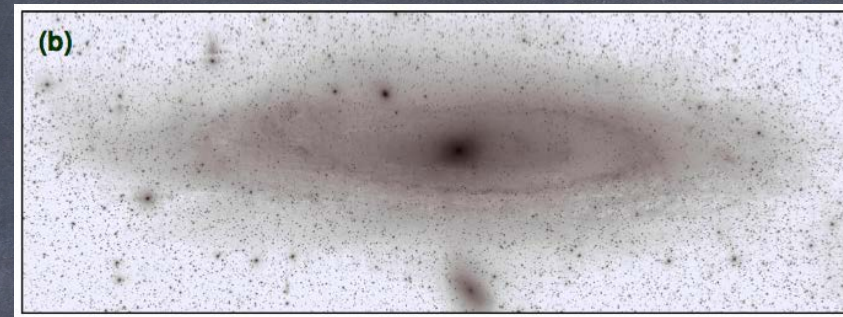- ... use dust disc to estimate the sign of inclination

Fig. 1. Geometry of the dust disc model. The line-of-sight optical depth for three positions A−C is indicated. The figure is illustrative only.

Tempel, Tamm, Tenjes (2010)
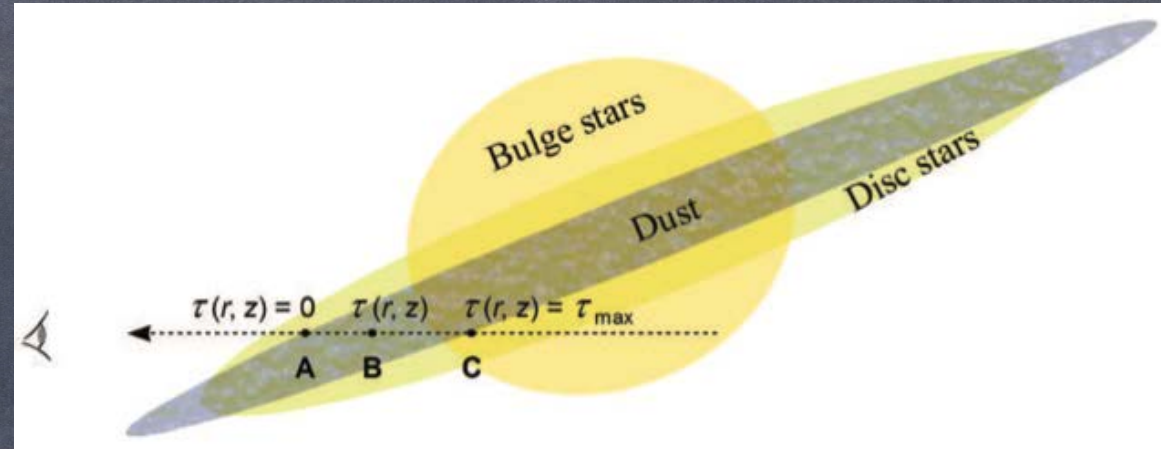
Tempel, Tuvikene, Tamm, Tenjes (2011)

Tamm, Tempel, Tenjes, Tihhonova, Tuvikene (2012)

Dust extinction in spiral galaxies

Model for dust attenuation calculation in galaxies

Attenuation depends on:
 galaxy viewing angle,
 galaxy stellar structure,
 dust disc geometry and
 dust properties.

$$l(a) = l(0) \exp\left[-\left(\frac{a}{ka_0}\right)^{1/N}\right]$$

$$L(X,Y) = \int_X^\infty \frac{\sum_{j=1}^{2}\left[l(r,z_j)\,e^{-\tau(r,z_j)}\right]}{\sin i \sqrt{r^2 - X^2}} r\,dr$$

$$z_{1,2} = \frac{Y}{\sin i} \pm \frac{\sqrt{r^2 - X^2}}{\tan i},$$

$$\tau(r,z) = \tau_{\max}(X,Y)\frac{\int_A^B n_{\text{dust}}(s)\,ds}{\int_A^C n_{\text{dust}}(s)\,ds}$$

$$n_{\text{dust}}(r,z) = f_{\text{dust}}(r) \cdot n(a)$$

$$\tau_{\max,f}(X,Y) = c_{f,\lambda',T'}F_{\lambda'}(X,Y)\frac{\lambda^\beta B(\lambda',T')}{(\lambda')^\beta B(\lambda, T(X,Y))}$$
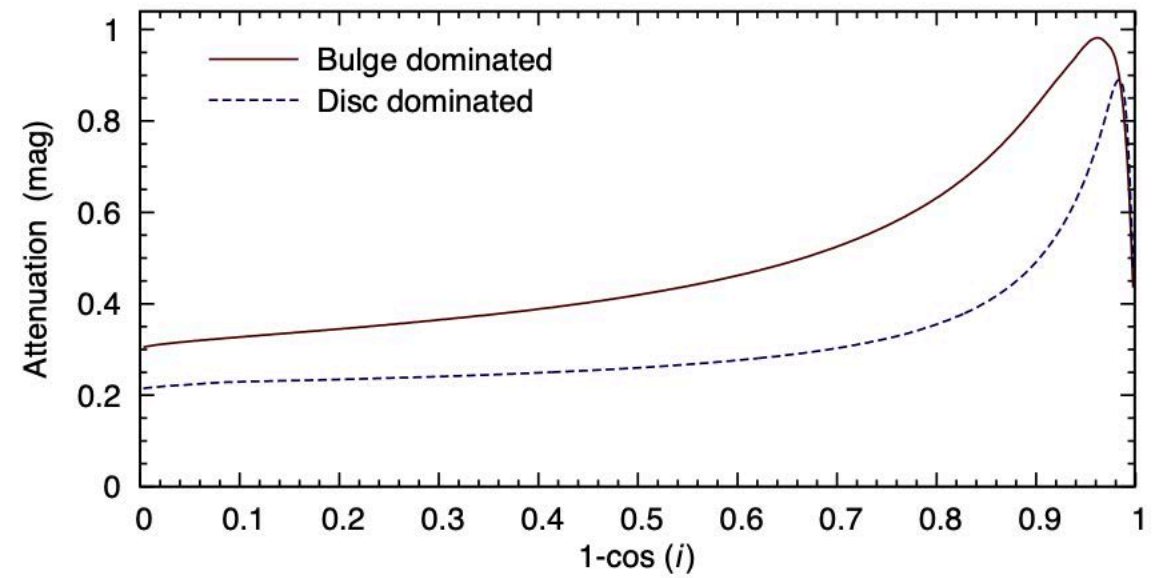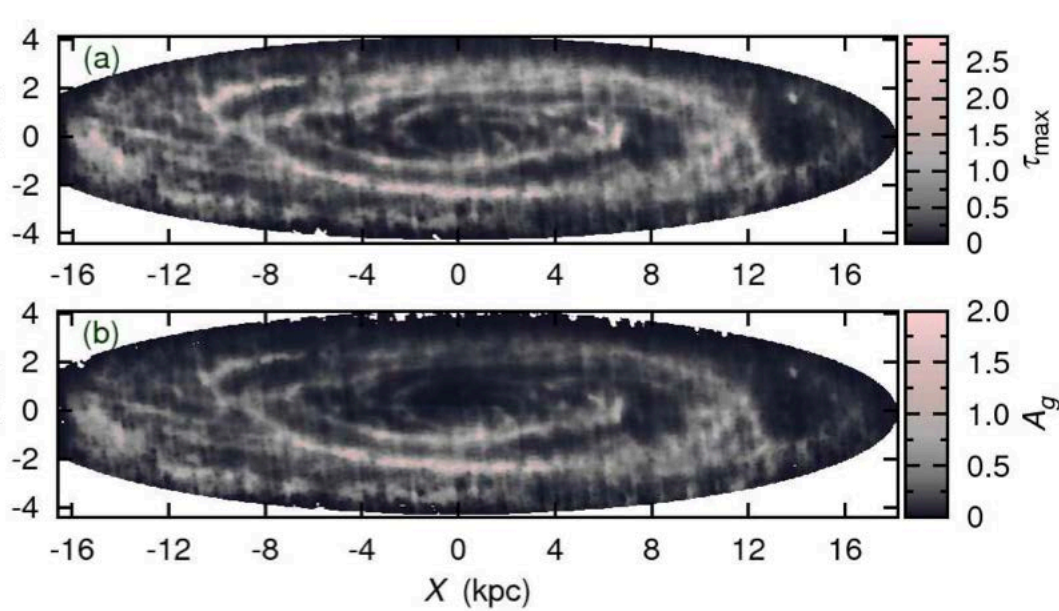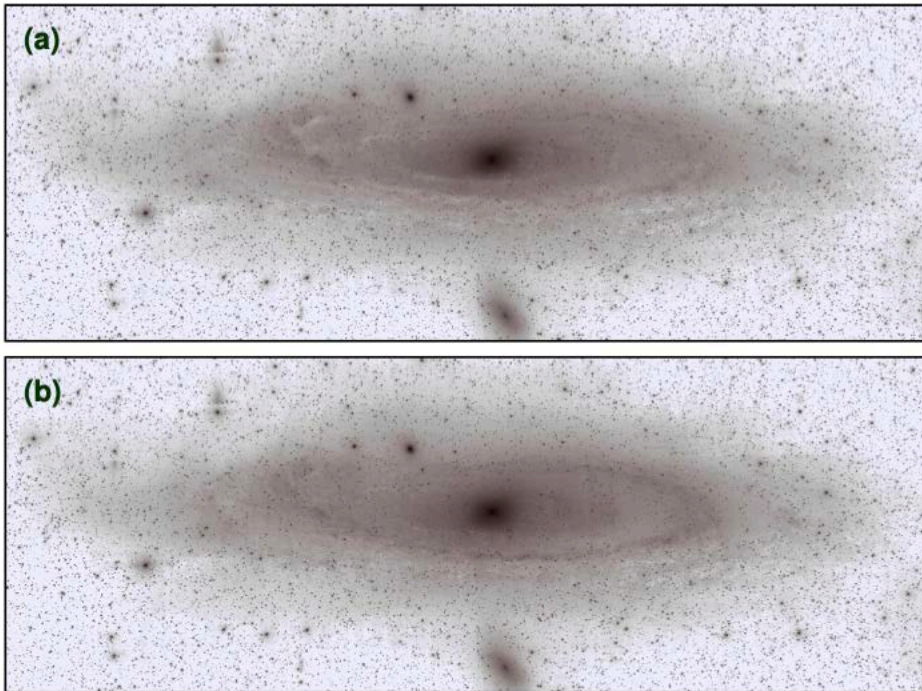
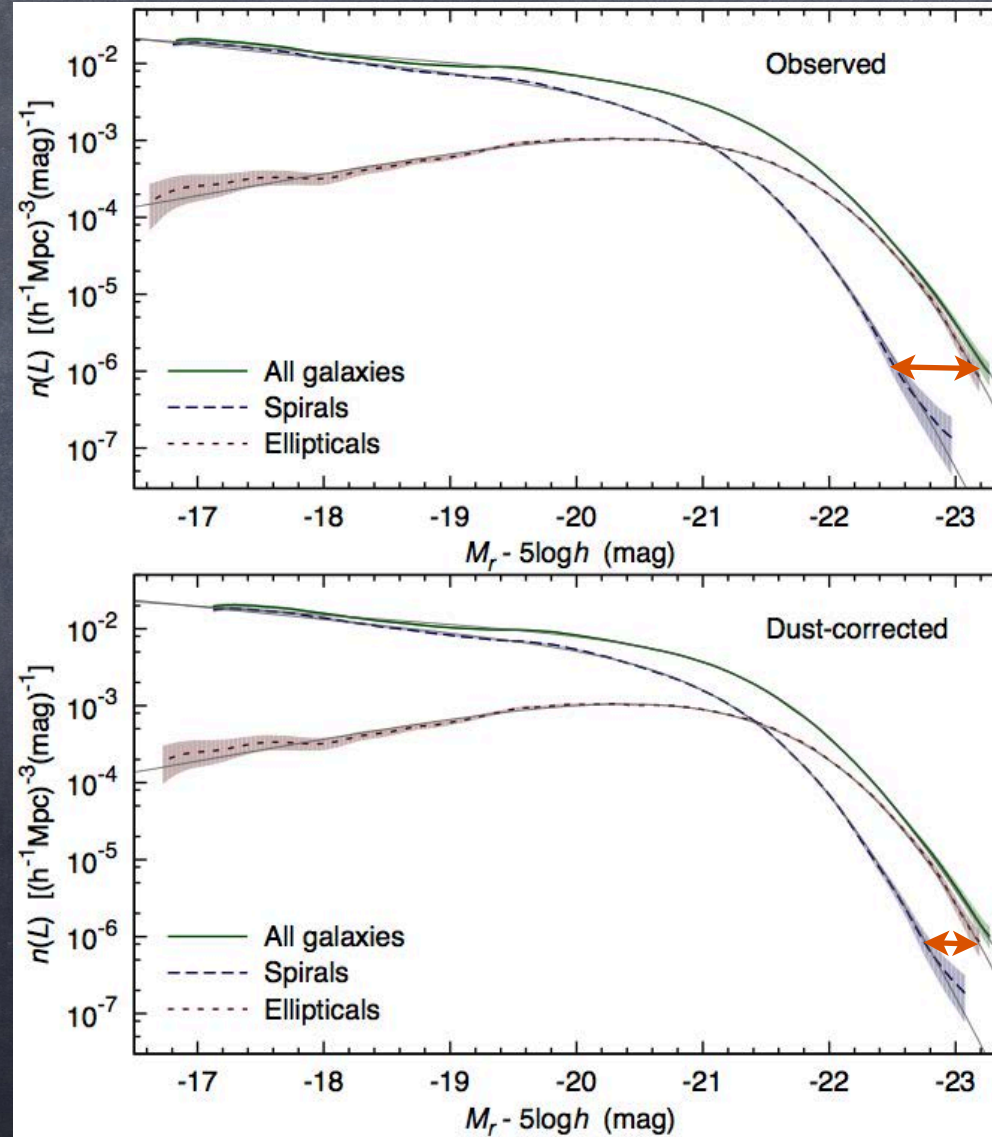Fig. 9. The dependence of attenuation on galaxy inclination for disc-dominated and bulge-dominated spiral galaxies.

Is 3D modelling necessary?

$$\cos^2(i) = \frac{(a/b)^2 - q^2}{1 - q^2}$$

a/b – visible axial ratio

q – disc flatness (0.1)

ET et al. 2011

Dust extinction: luminosity function

Redshift-space distortion (RSD)

Peculiar motion of galaxies distort the observed (redshift-space) galaxy distribution

$$z_{obs} = z_{true} + \delta v/c$$

(crossed out)
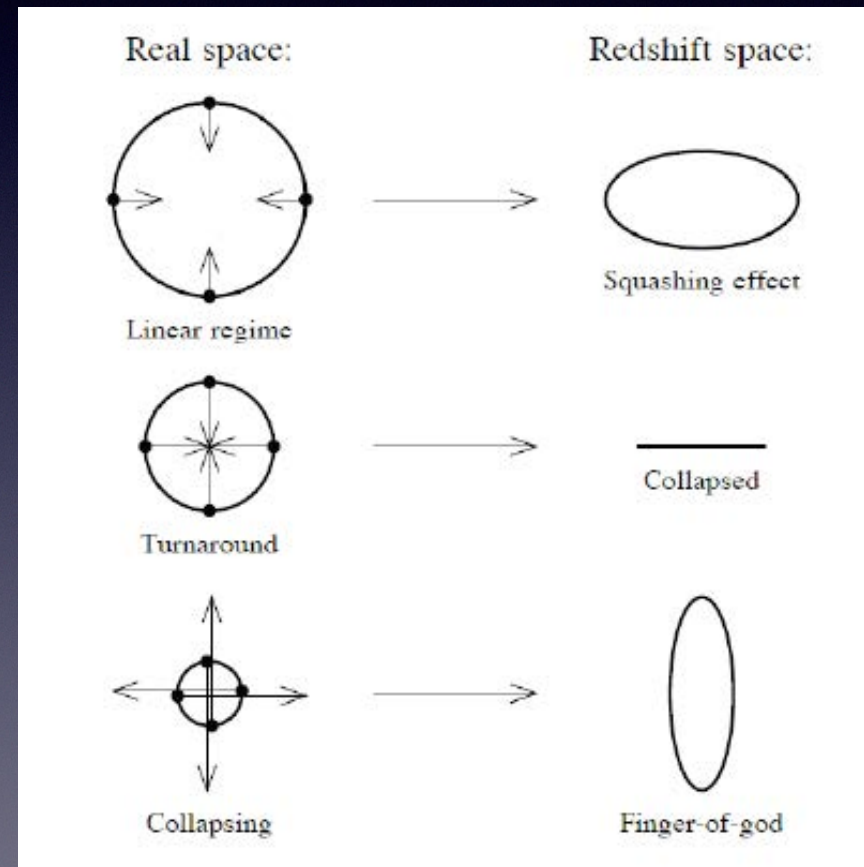
<u>Linear regime</u>
Coherent bulk motion squashes the galaxy distribution along the LOS direction
"Kaiser effect"

<u>Nonlinear regime</u>
Random motion of galaxies elongate the galaxy distribution along the LOS direction
"Fingers-of-God effect"

Real space: / Redshift space:
Linear regime — Squashing effect
Turnaround — Collapsed
Collapsing — Finger-of-god

Hamilton 1992

line-of-sight direction

Test of Gravity

Redshift-space galaxy power spectra
in linear regime

2-point correlation functions for
BOSS CMASS samples $\xi(r_p, r_\pi)$

$$P_{\mathrm{g}}(k,\mu) = (b + f\mu^2)^2 P_{\mathrm{m}}(k) \quad (\text{Kaiser 1987})$$

b: linear galaxy bias $\mu = k_{\parallel}/k$
f: growth rate

Growth rate is a key probe to test gravity

$$f \equiv \frac{d \ln D}{d \ln a} \simeq \Omega_m(z)^\gamma$$
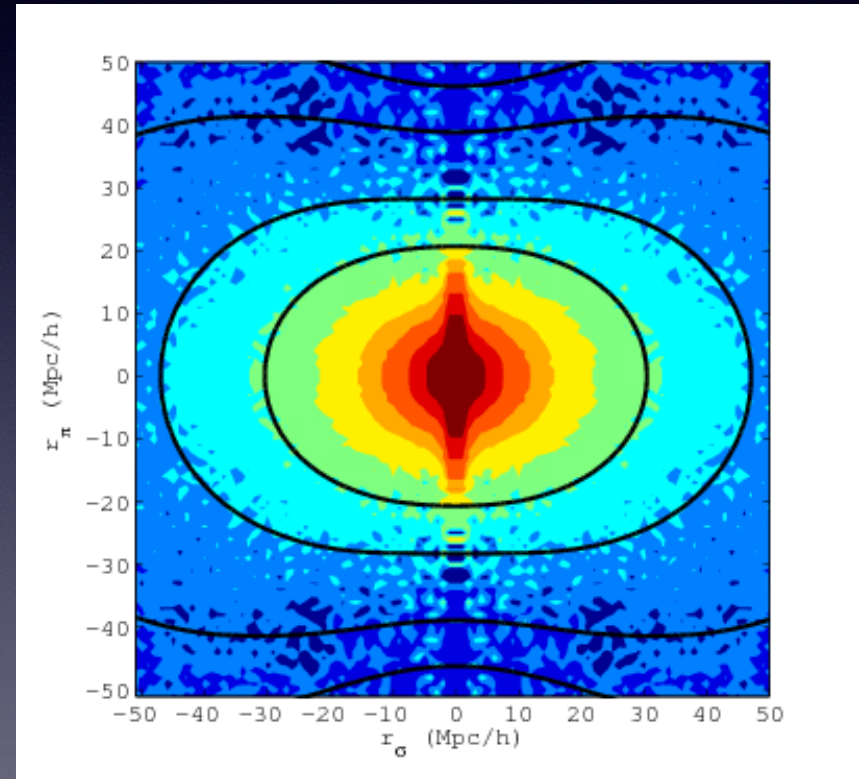
(Peebles 1976, Lahav et al. 1991)

$a = 1/(1+z)$

$D(a)$ - linear
growth factor

$\gamma \simeq 0.55$ for ΛCDM

$\gamma \simeq 0.68$ for flat DGP (e.g., Linder & Cahn 2007)

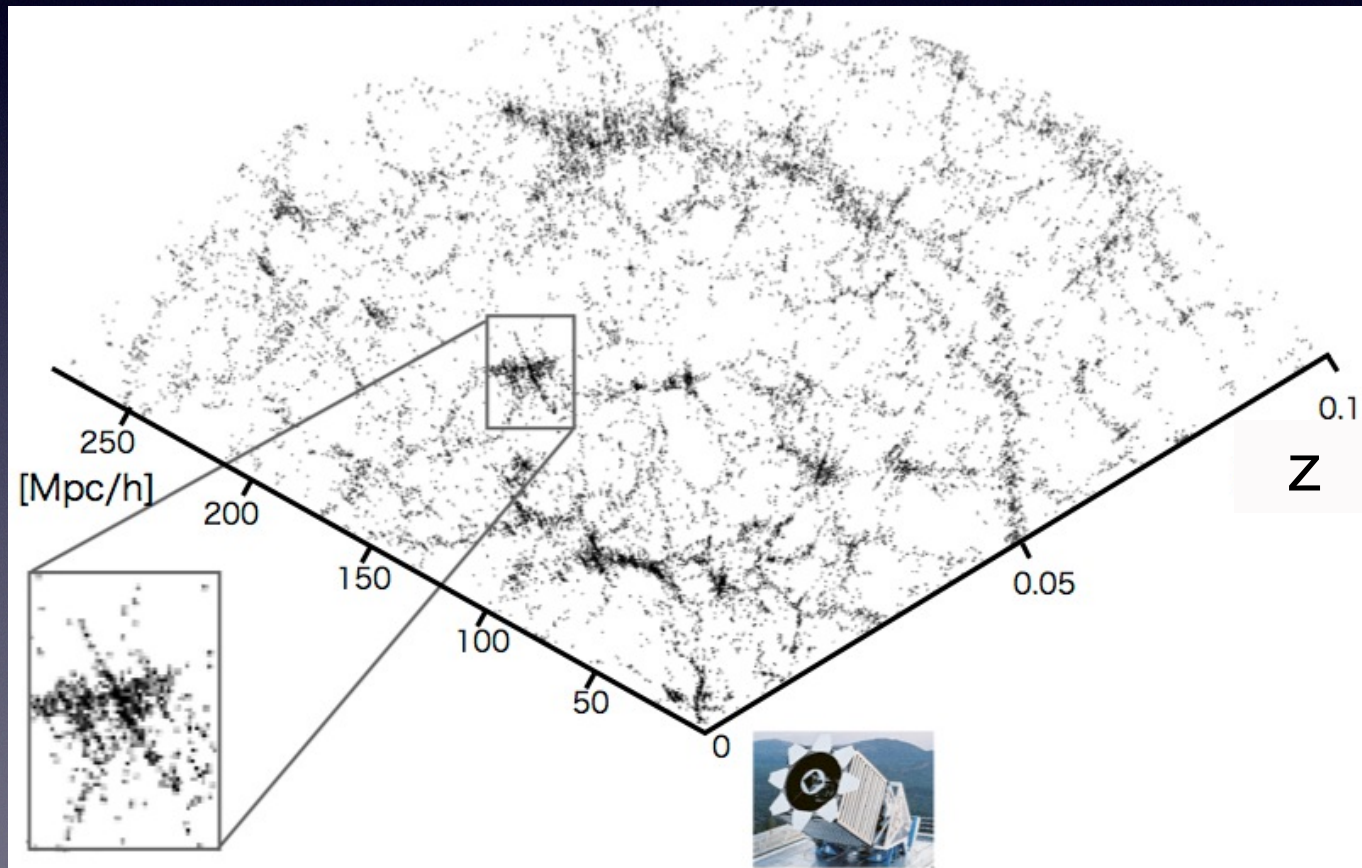$\gamma \simeq 0.43$ for $f(R)$ (e.g., Hu & Sawicki 2007)

Reid et al. 2012

line-of-sight
direction

Fingers-of-God (FoG) effect

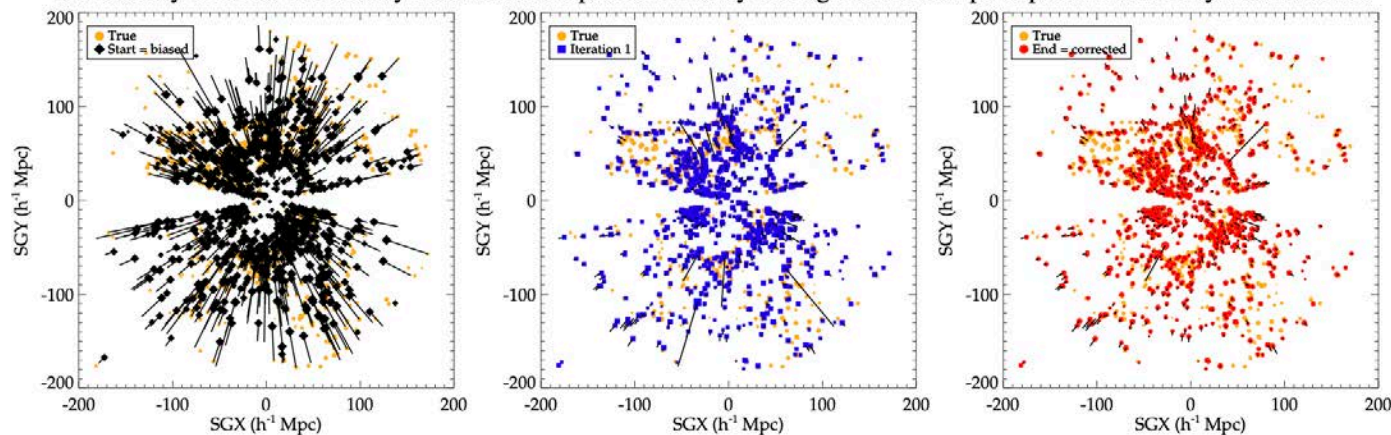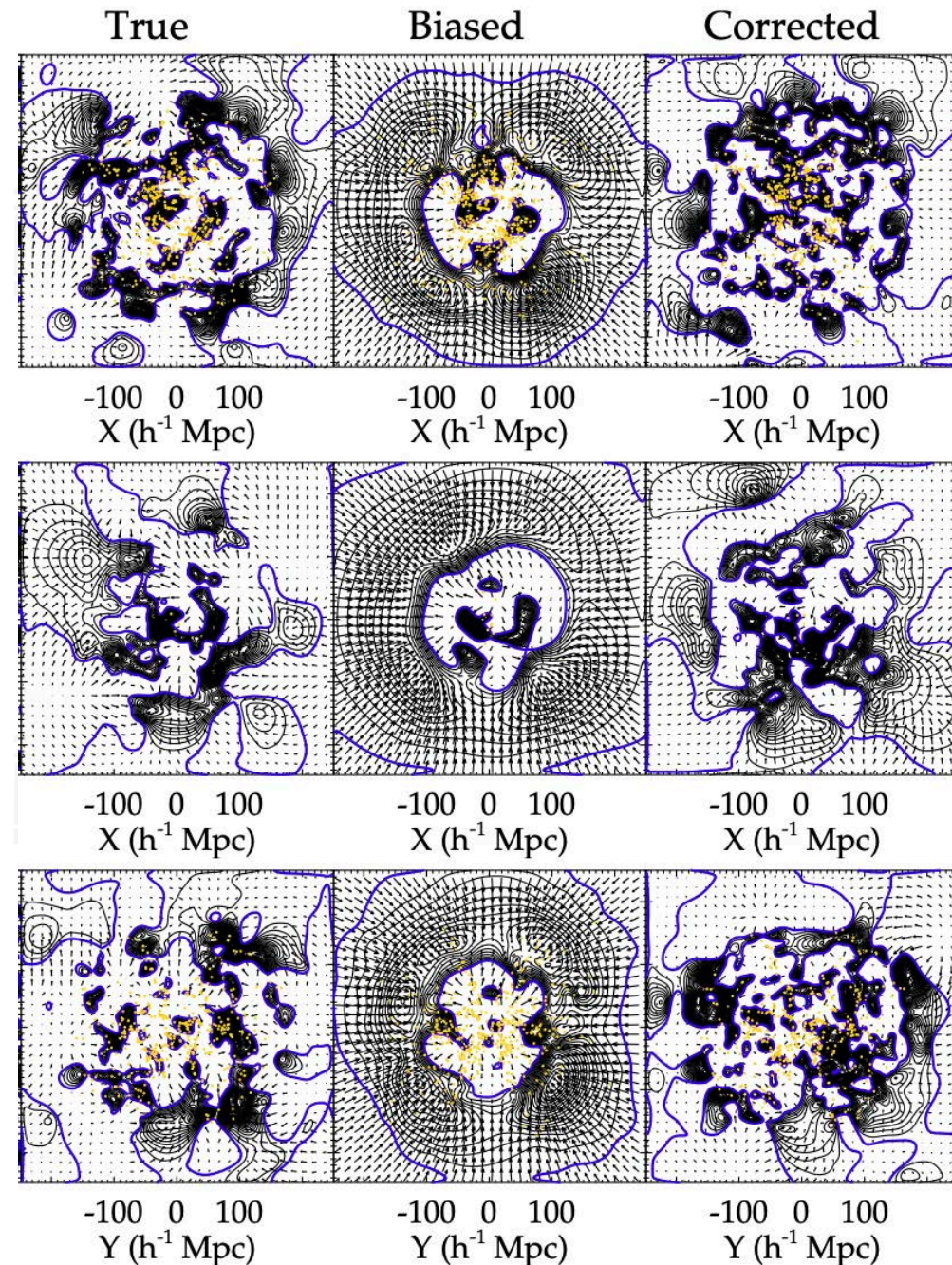Nonlinear redshift-space distortion due to internal motion of galaxies in the host halos

Sorce Jenny G. et al.: Statistically bias-minimized peculiar velocity catalogs from Gibbs point processes and Bayesian inference

Fig. 4. Galaxies in 5 h^{-1} Mpc thick slices of the XY supergalactic plane. *From left to right*: Black lines show the projected distances between true (yellow filled circles) and biased (black filled diamonds), after n_{mh} Metropolis Hastings loops but no cooling for the n datapoints (in the text Iteration 1, blue filled square) and, at the end of all loops (red filled circles), datapoint positions. The filled symbol sizes are proportional to velocities on a logarithmic scale. Note that because errors are large in the left panel, yellow filled circles are harder to distinguish. The algorithm reduces on the average errors on datapoint positions thus on their peculiar velocities: on average shorter black lines and by extension better matching filled symbol sizes of different colors.

Biased velocity field

Sorce et al.

Galaxy Groups in redshift surveys

UNIVERSITY OF TARTU

WAVES-Deep

z~0.20

222   220   218   216   214   212

2MASS Extended Source Catalog Red

SGZ (km/s)
15000
10000
5000
0
-5000
-10000
-15000

SGX (km/s)
15000
10000
5000
0
-5000
-10000
-15000

SGY (km/s)
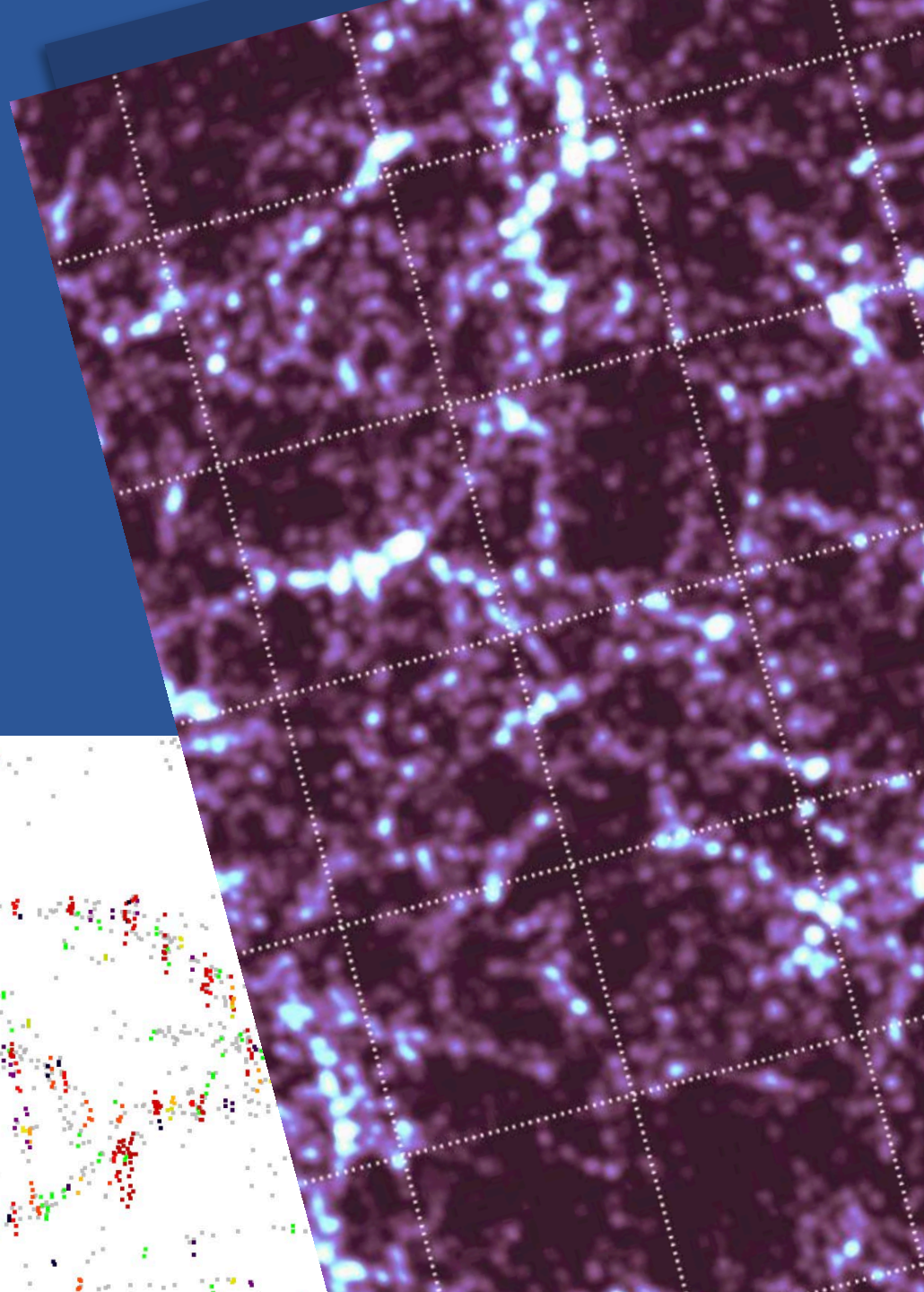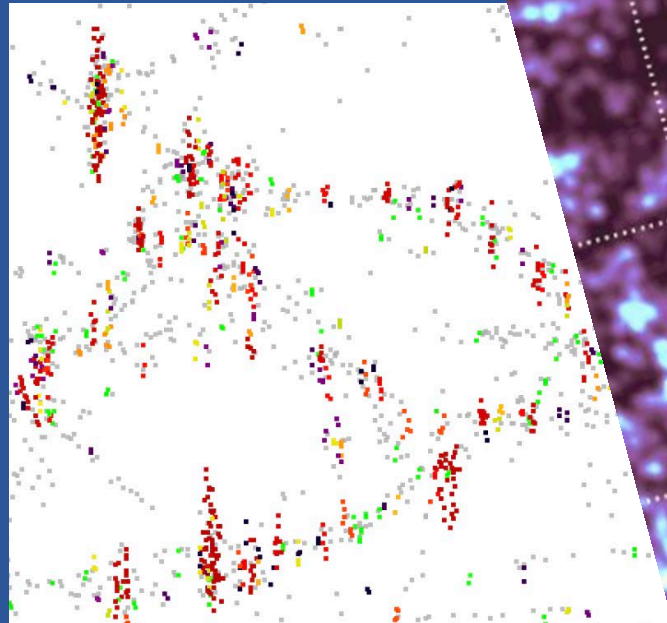15000 10000 5000 0 -5000 -10000 -15000
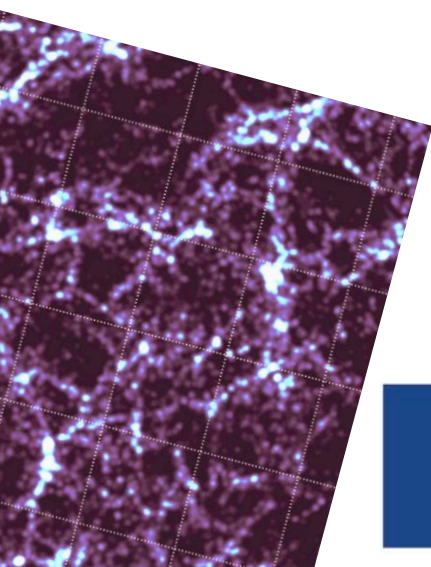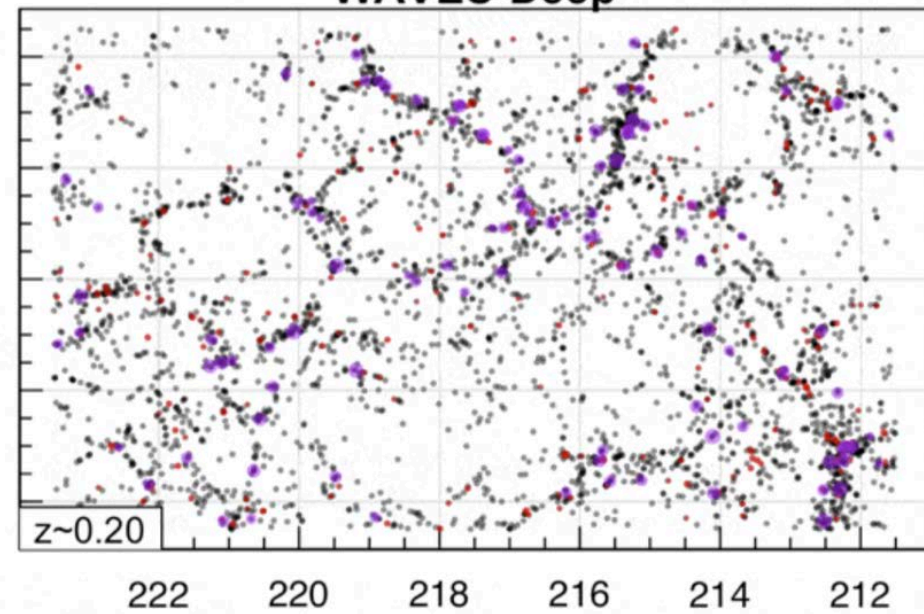
Cosmic Web in 3D

Cosmic web in the Local Universe
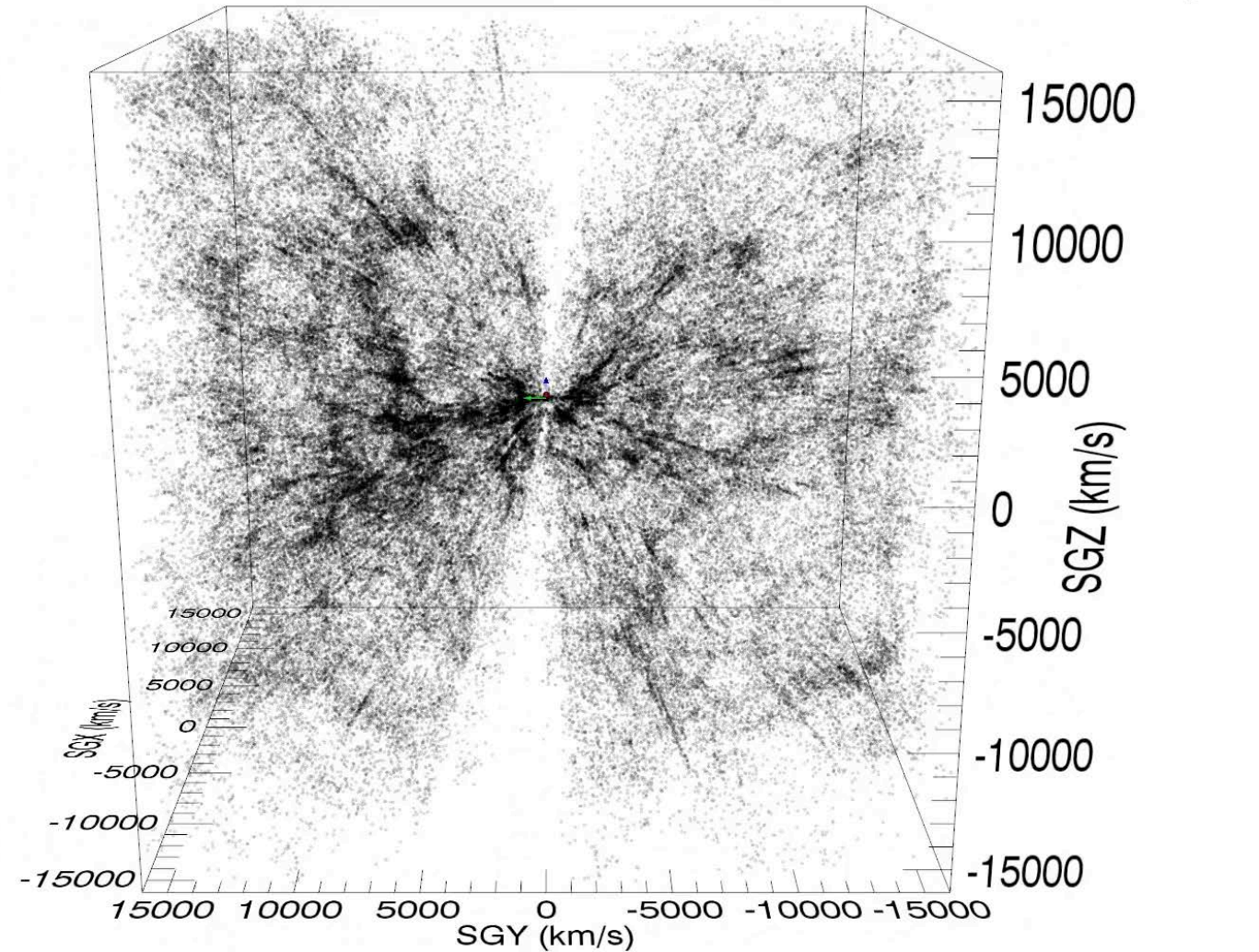
Group finding: three aspects

- **Where are the groups?**
  Finding the group centres

- **What galaxies belong to the groups?**
  Group membership assignment

- **Estimating group properties**
  (i.e. group masses)

Impact of grouping

Tully Grouping, $H_0 = 73$ km s^{-1} Mpc^{-1}

Tempel Grouping, $H_0 = 73$ km s^{-1} Mpc^{-1}
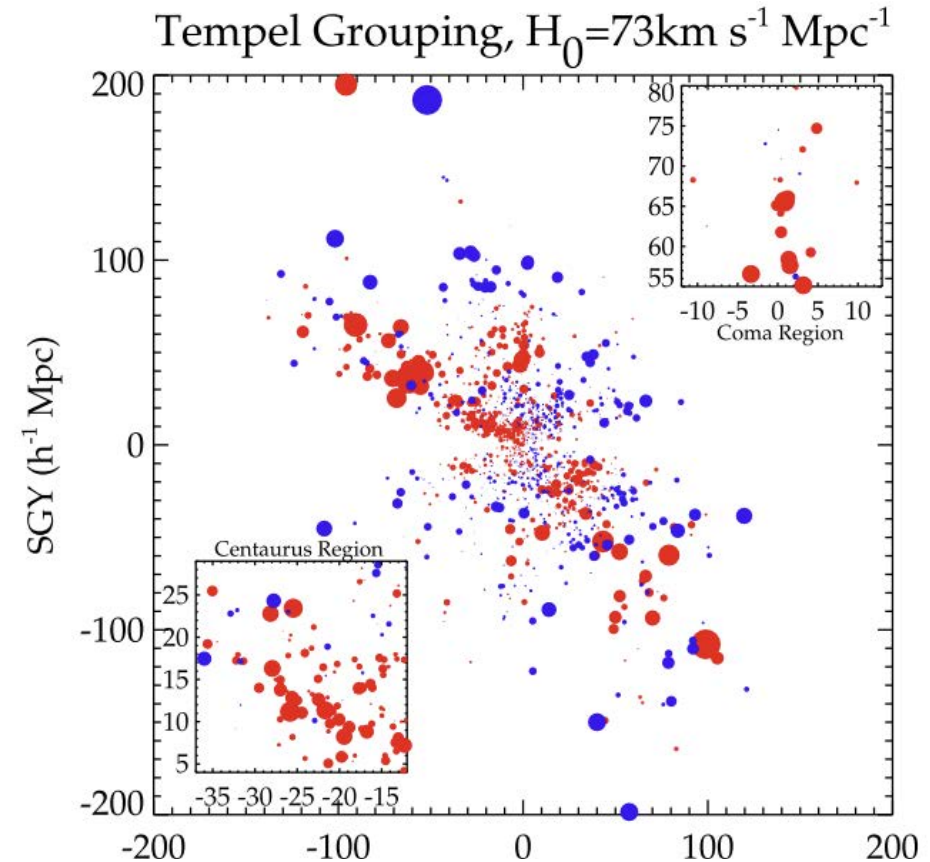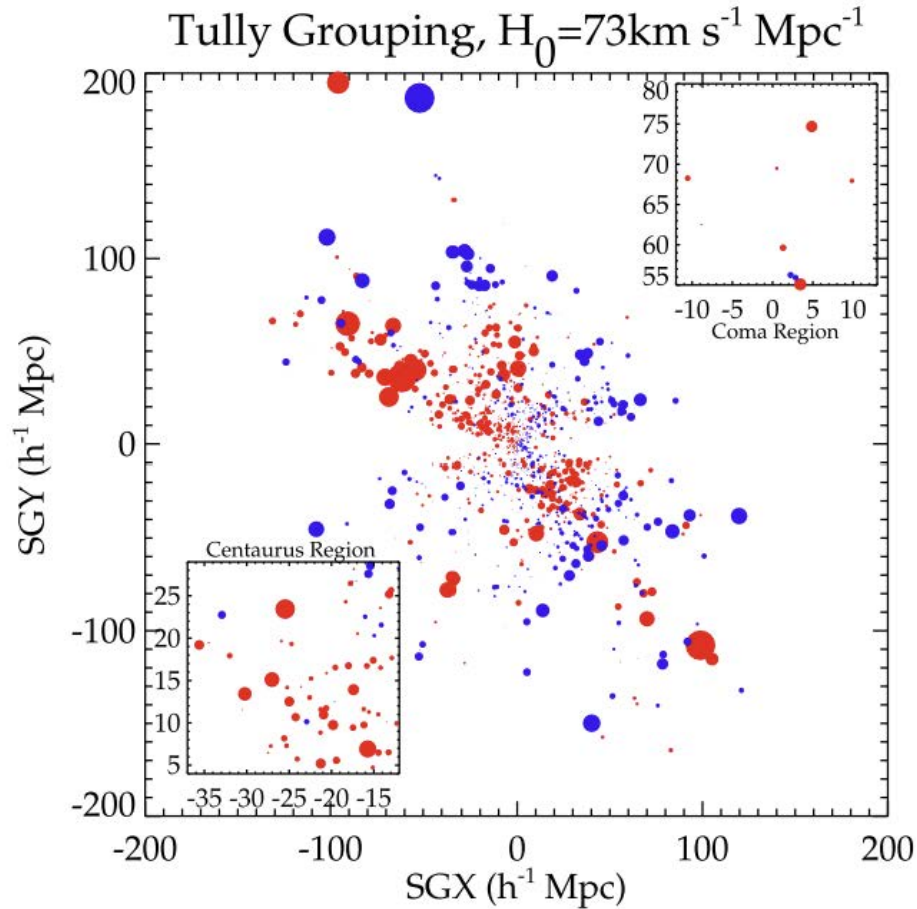
How does the grouping scheme affect the Wiener Filter reconstruction of the local Universe?

Jenny G. Sorce[1,2]★ and Elmo Tempel[2,3]

[1] CNRS, Observatoire astronomique de Strasbourg, UMR 7550, Université de Strasbourg, F-67000 Strasbourg, France
[2] Leibniz-Institut für Astrophysik, An der Sternwarte 16, D-14482 Potsdam, Germany
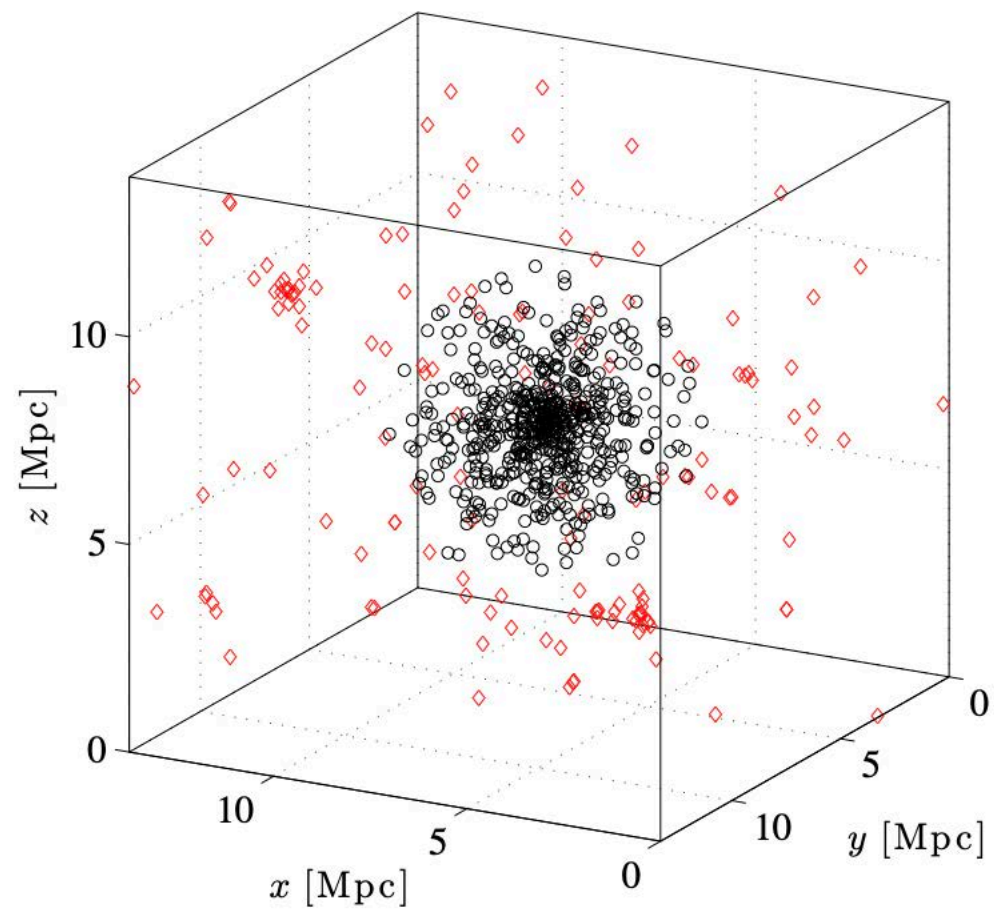
Interlopers

Old et al.

$$\mathcal{F}_{\rm gal} = \frac{N_{\rm gal}^2({\rm HALOS} \cap {\rm FOF})}{N_{\rm gal}({\rm HALOS})\, N_{\rm gal}({\rm FOF})},$$
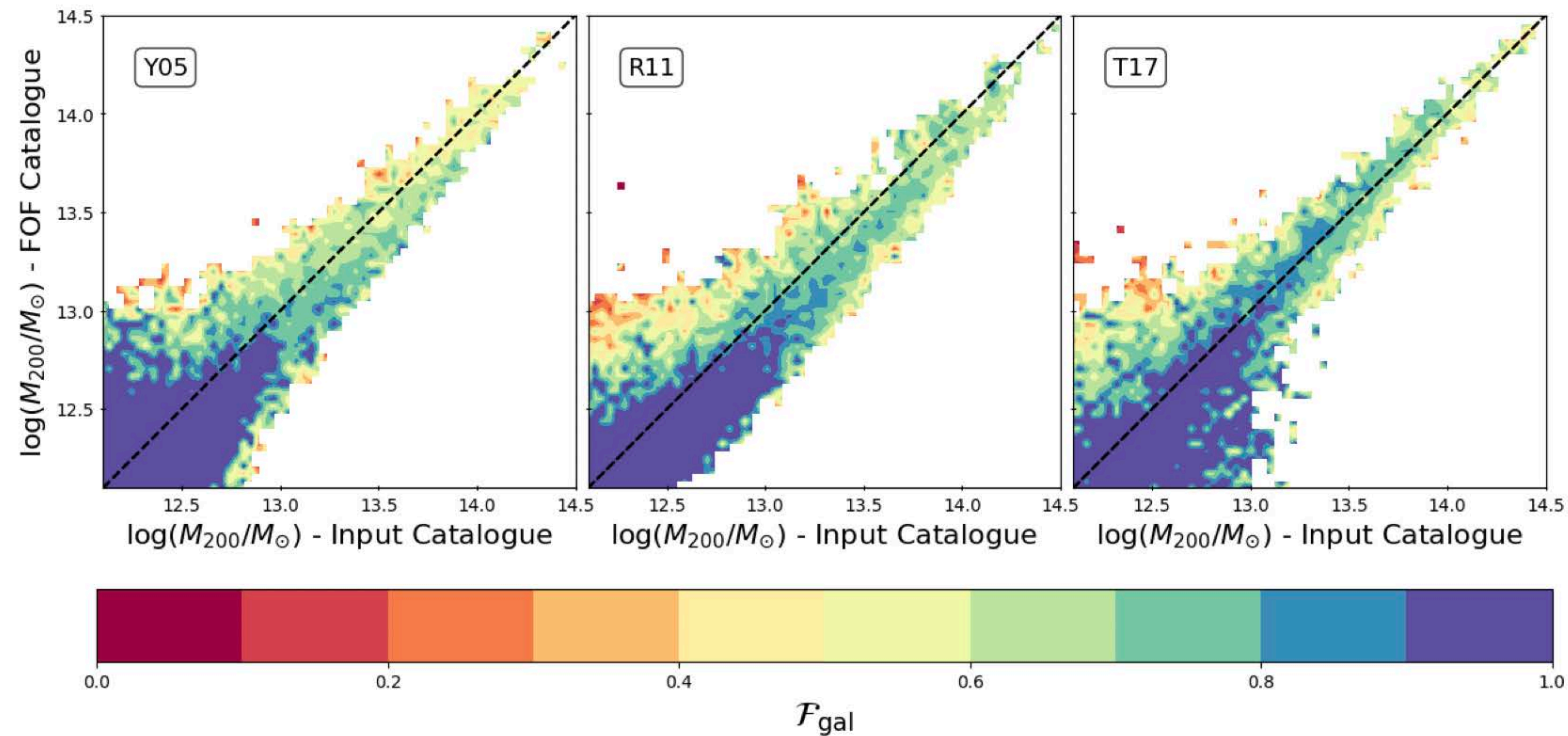
Estimated group masses

Marini et al. 2025, Popesso et al. 2025

Old et al.

Estimated group masses

SDSS groups at z < 0.08
Multiplicity > 4
N groups = 4847

- ● SDSS z<0.08 Corrected HMF
- ◇ SDSS z<0.08 Raw HMF
- — Best MRP function fit
- -- LCDM prediction
- — SDSS DR10 (Tempel+ 2014)

$\log_{10}$ (umber density) [Mpc^{-3} dex^{-1}]

Halo Mass ($M_\odot$)
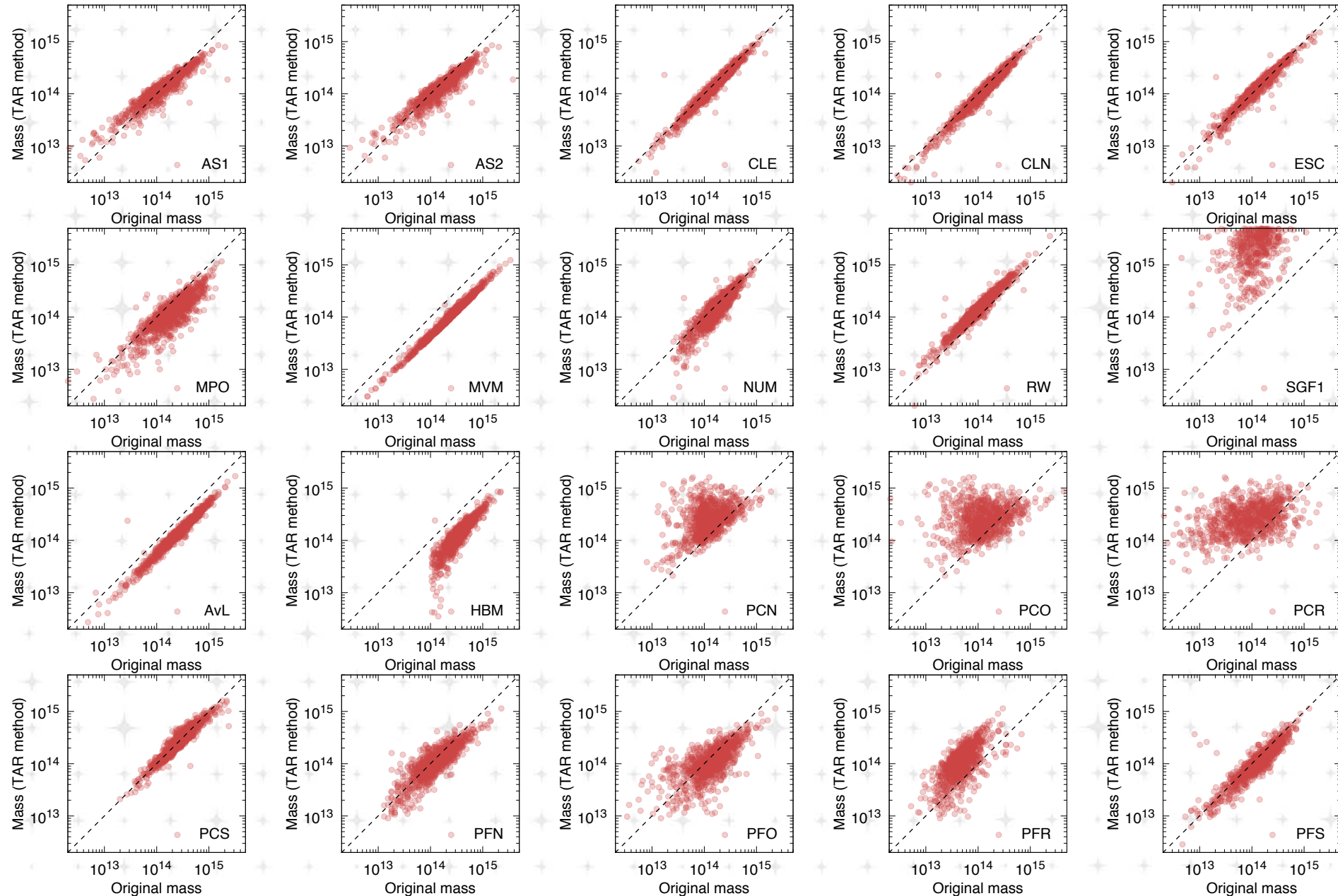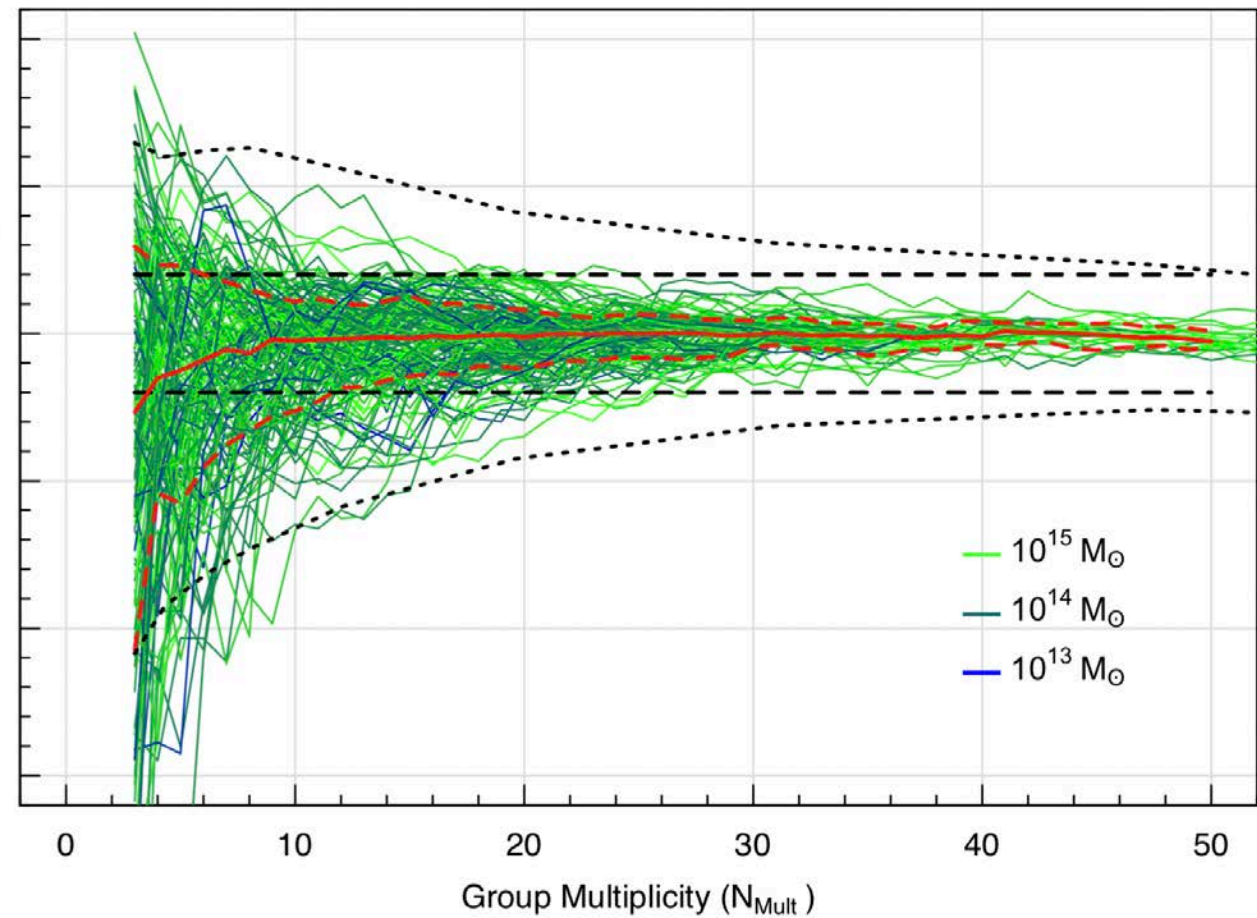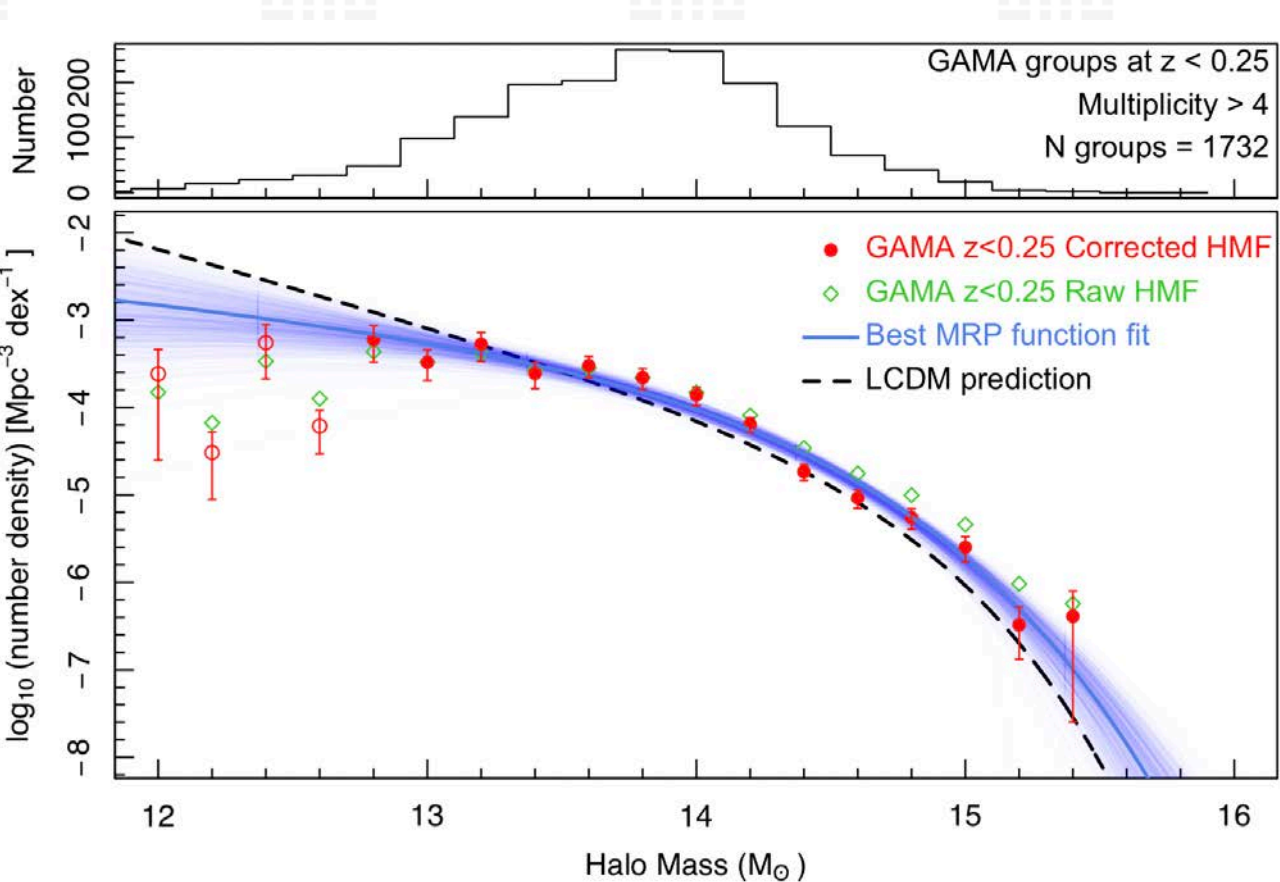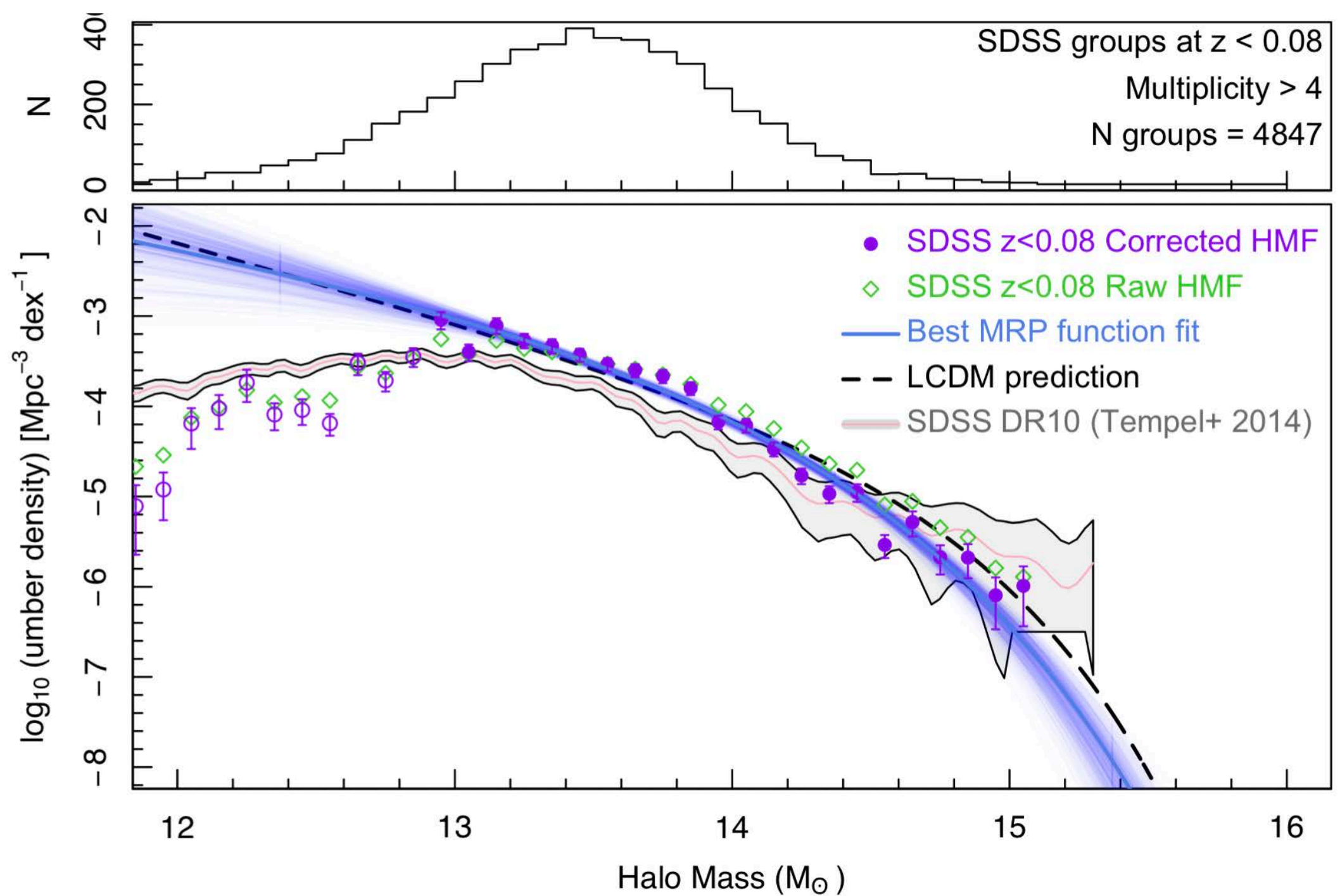
Estimating group masses:

observed properties of groups

$$\sigma_v^2 = \frac{1}{(1 + z_m)^2(n - 1)} \sum_{i=1}^{n} (v_i - v_{mean})^2$$

Radial velocity dispersion in the group.

v = cz

$$\sigma_r^2 = \frac{1}{2n(1 + z_m)^2} \sum_{i=1}^{n} (r_i)^2$$

Group extent in the sky:
r_i in co-moving coordinates,
1/2n since Rayleigh distribution

Dynamical mass estimate

- From virial theorem (no free scaling parameters)

$$T = \frac{M_{\text{tot}}\sigma_v^2}{2}, \qquad U = G\frac{M_{\text{tot}}^2}{R_g}, \qquad 2T = U$$

T kinetic energy
P potential energy

$$M_{\text{vir}} = 2.325 \frac{R_g}{\text{Mpc}} \left(\frac{\sigma_v}{100\,\text{km s}^{-1}}\right)^2 10^{12} M_{\odot}.$$

R_g Gravitational radius, which is directly linked (e.g. assuming NFW profile) to the group size in the sky plane

σ_v Group velocity dispersion measured using galaxy redshifts

Estimating group masses:

virial theorem

Mass in units of $10^{12}M_{sun}$
R_g in units of Mpc
$sigma_v$ in units of 100 km/s

$$M_{tot} = 2.324 \cdot R_g \sigma_V^2$$

$$\sigma_V = \sqrt{3}\sigma_{V1D}$$

Velocity dispersion.

Gravitational radius (R_g):

$$\frac{1}{R_g} = \frac{4\pi}{M^2} \int_0^\infty \frac{M(r)}{r}\rho(r)r^2 dr.$$

Estimating group masses:
gravitational radius vs group extent in the sky

- We assume NFW profile.
- Mass-concentration relation from Maccio et al. (2008).
- $R_g = f(M_{200})$.
- For given mass M_{200}, we found R_g/sigma_R using NFW profile.
- Using this relation we transfer the observed group extent in the sky to gravitational radius R_g.
- We calculate the observed group mass using virial theorem.
- The final mass is found iteratively.

Groups in LC1
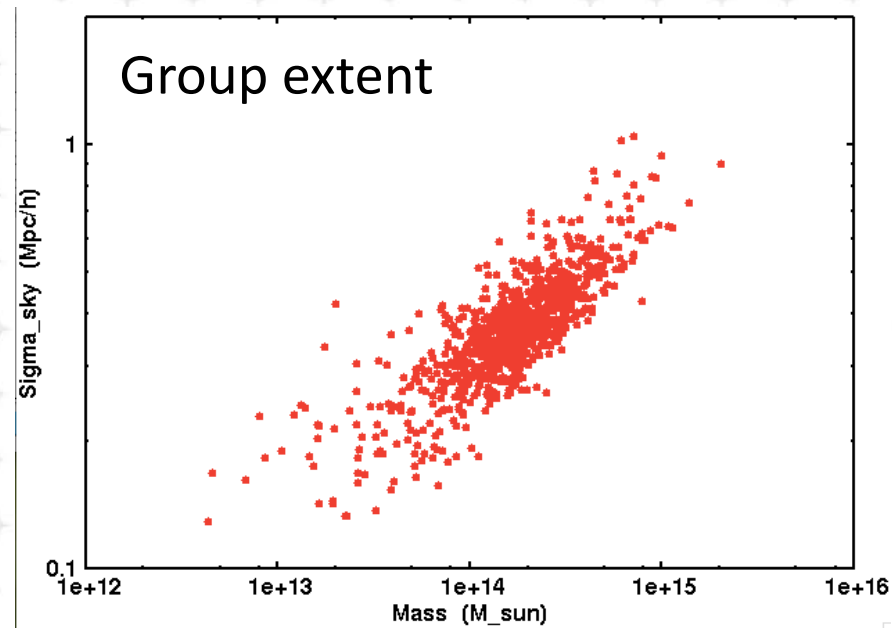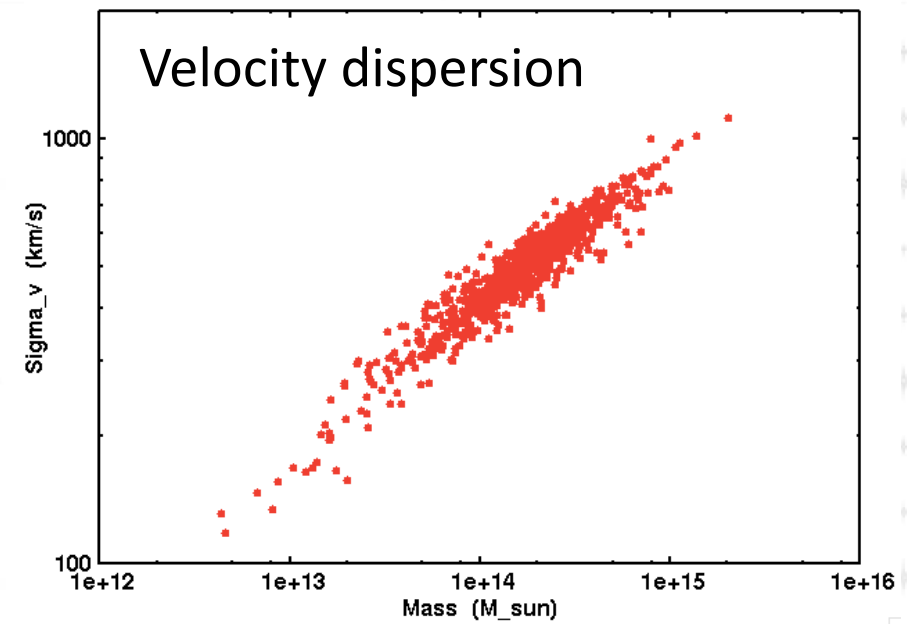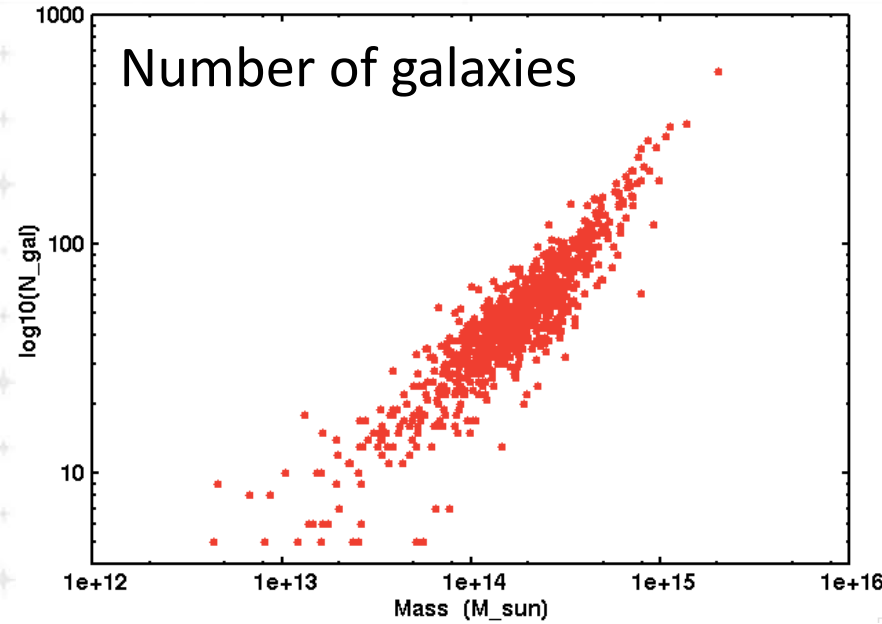
Merged Groups and Fingers-of-God

MHD = 0.0809 Mpc (12.8% of limit)
Centers distance = 2056 [kpc]

CfA: $0° < \delta < 30°$
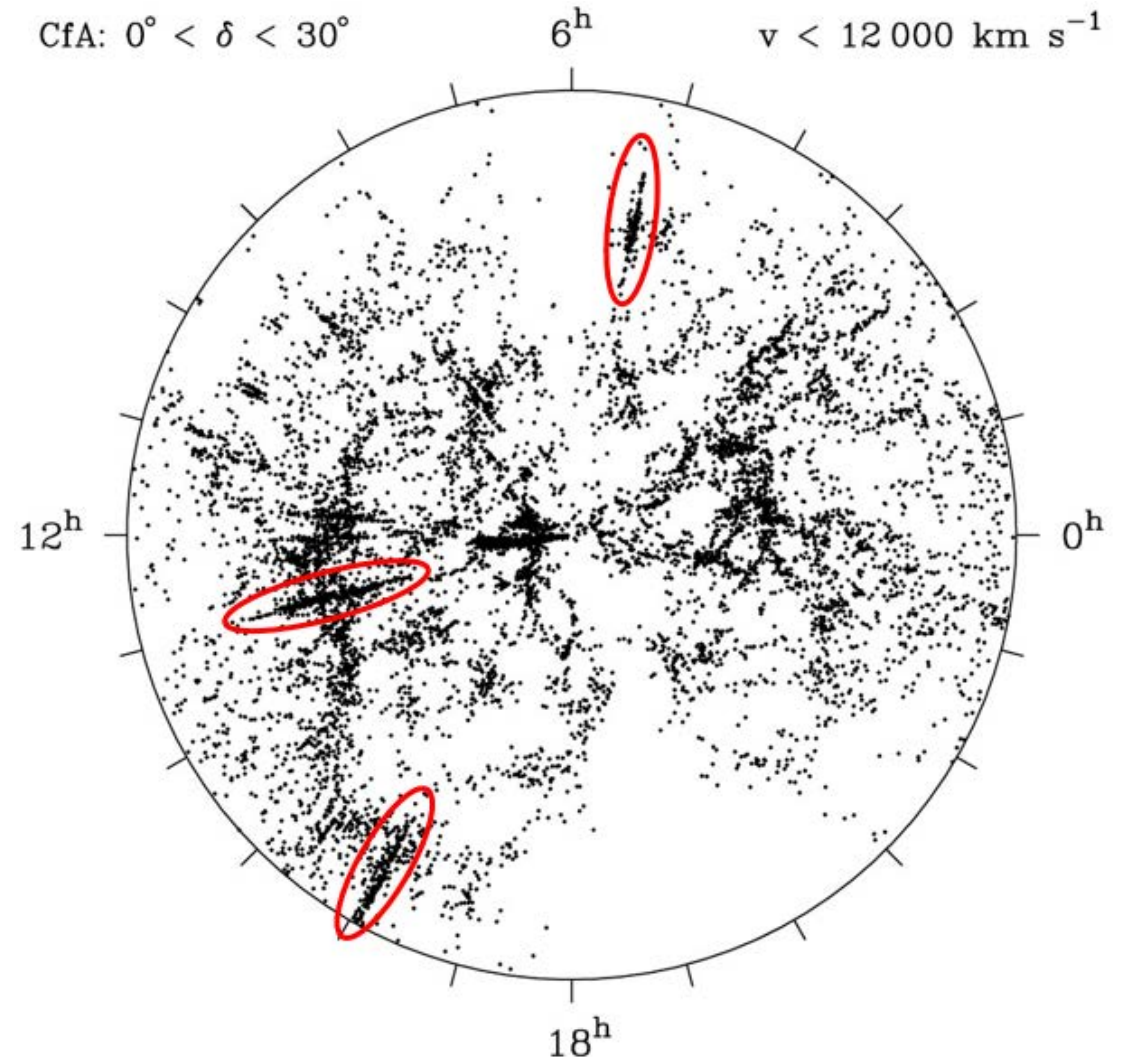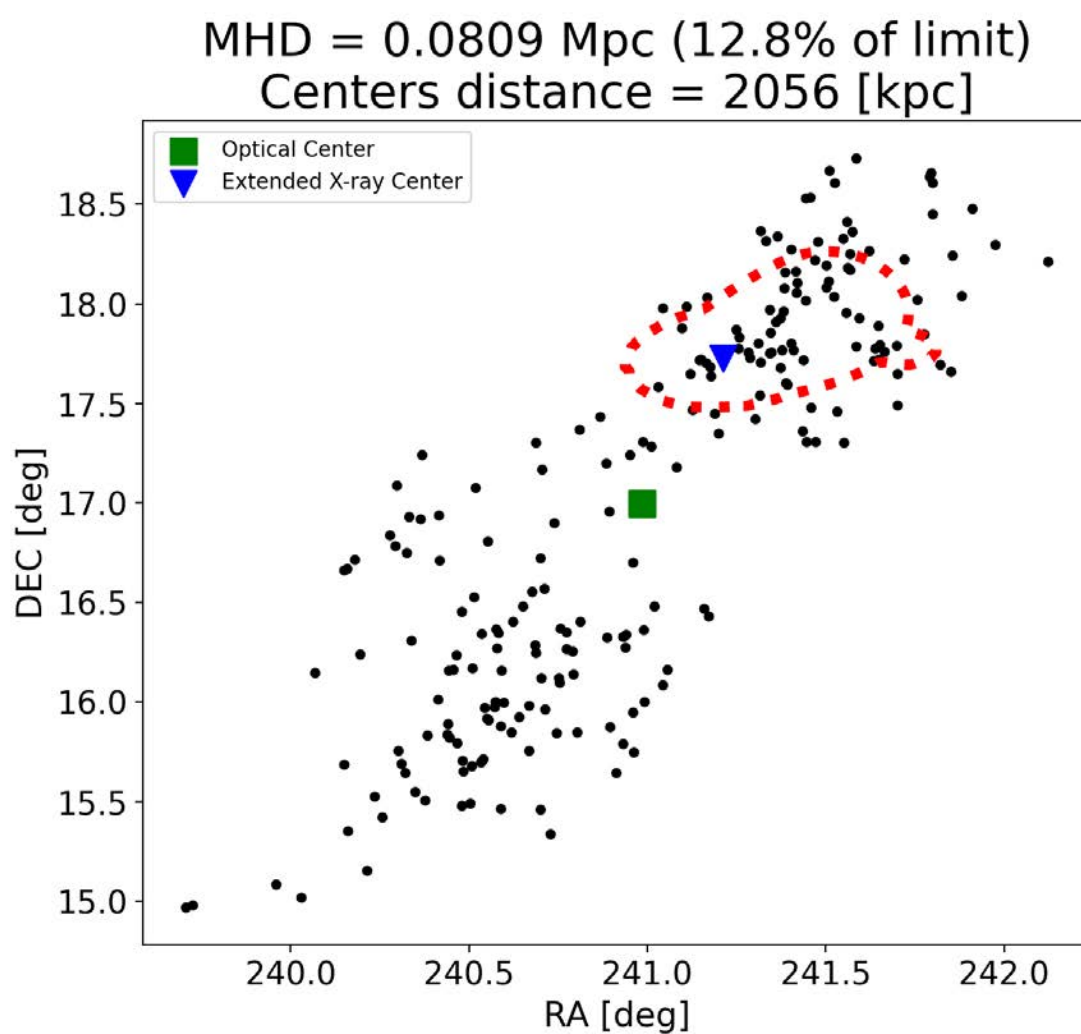
Improving Friends-of-Friends algorithm

Tempel et al. (2016)
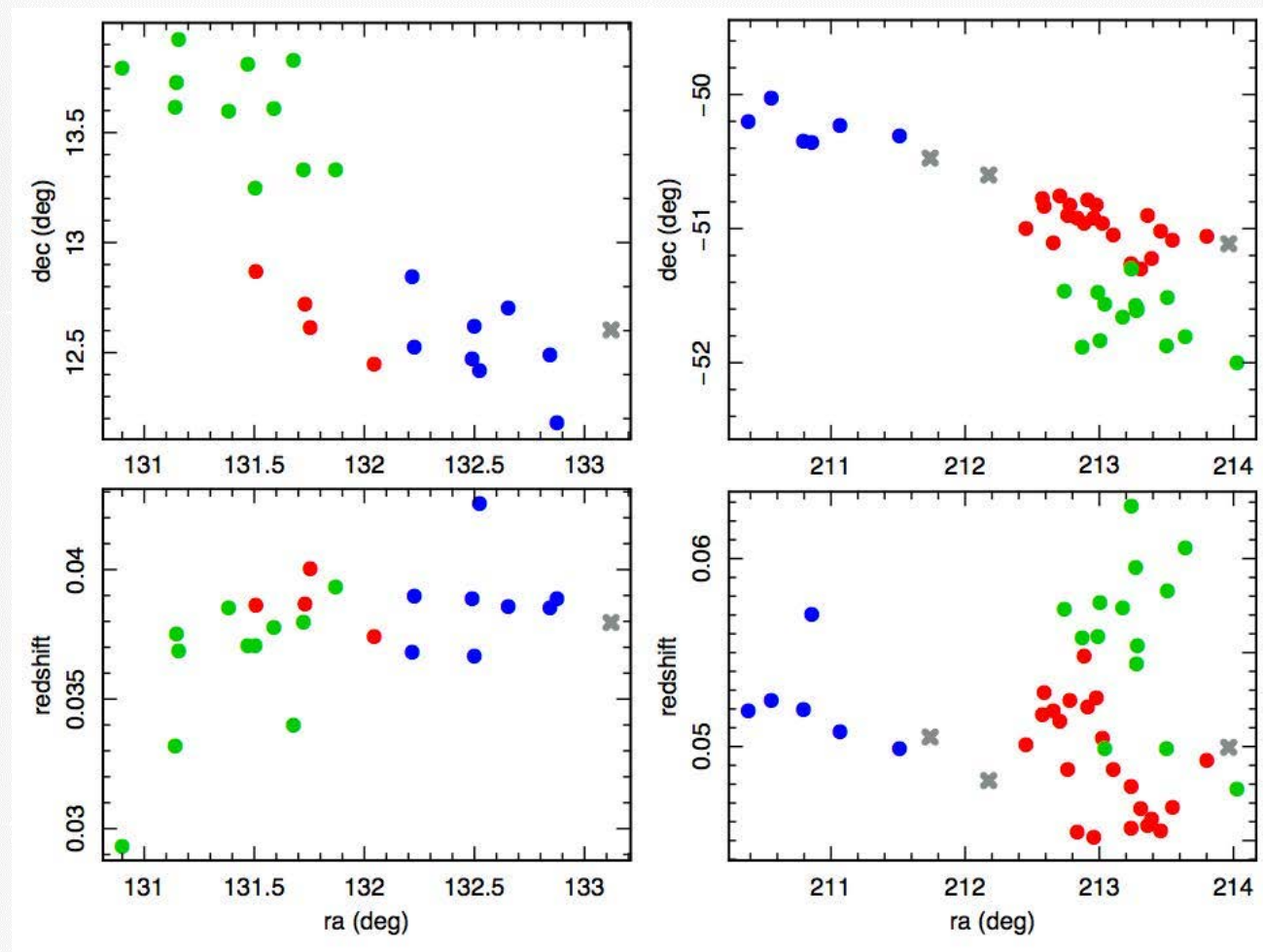
Friends-of-Friends Parameters
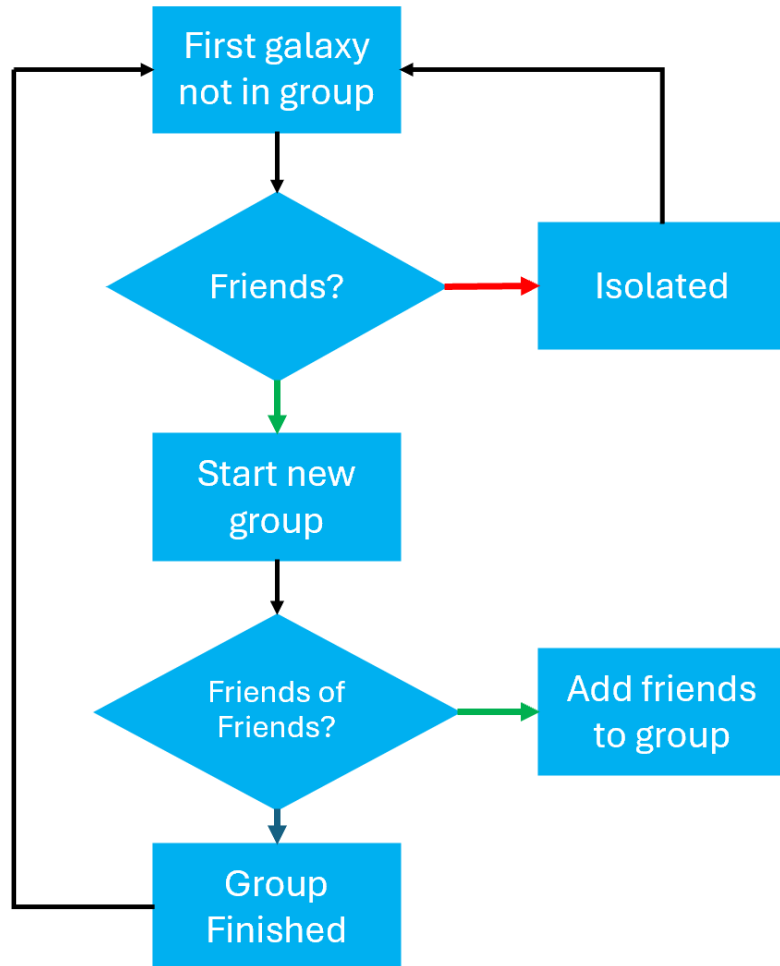
Used parameters

$$D_\perp$$

$$R = D_\parallel / D_\perp$$

Credit: Trystan Lambert
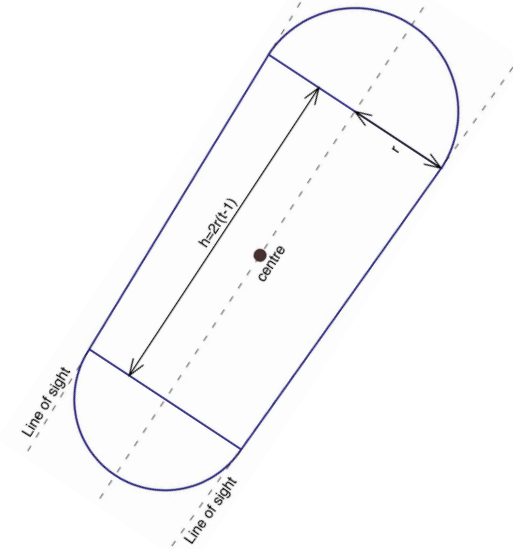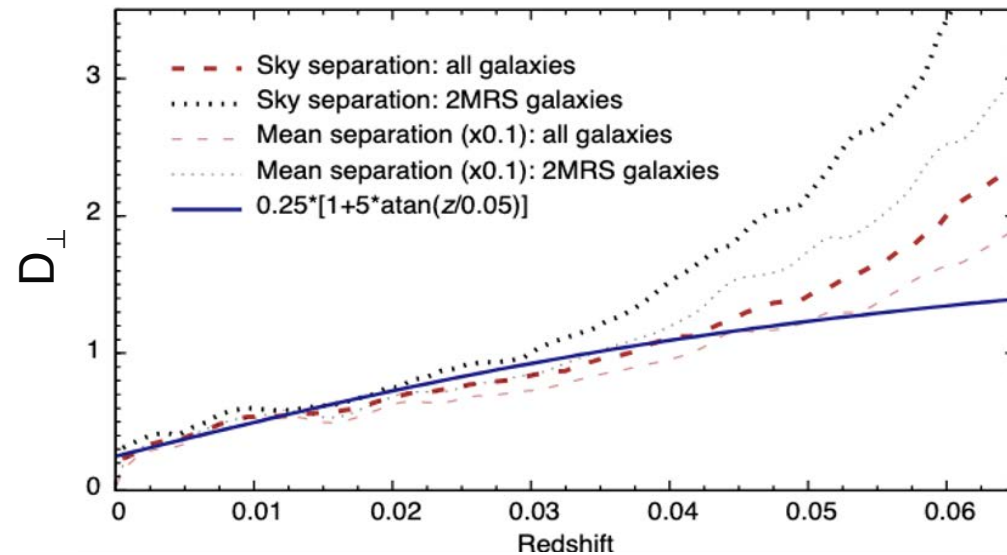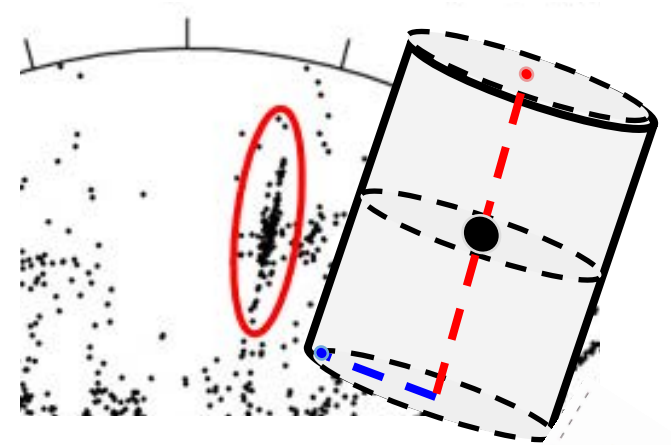
Friend-of-Friend group finder

$$LL \approx 0.1 \cdot \left(\frac{Volume}{N_{gal}} \right)^{1/3}$$

- Linking length depends only on the mean number density of galaxies

- Different linking lengths in the sky plane and along the line of sight.

- 10x larger linking length along the line of sight
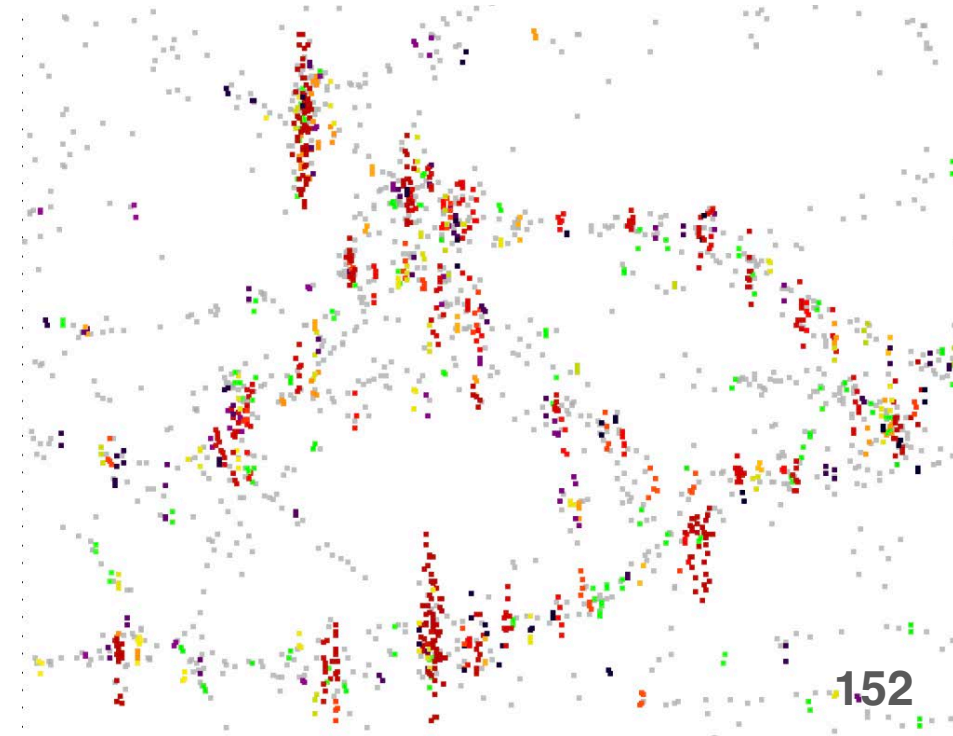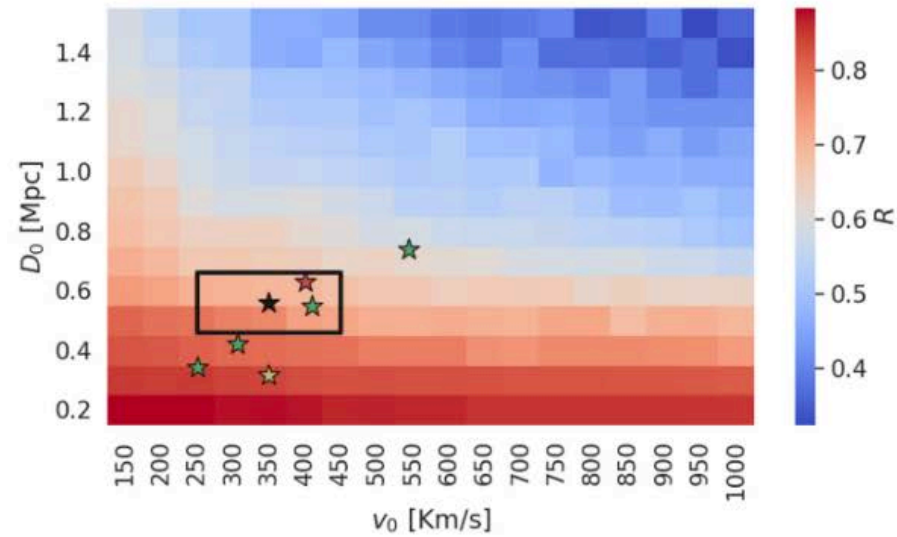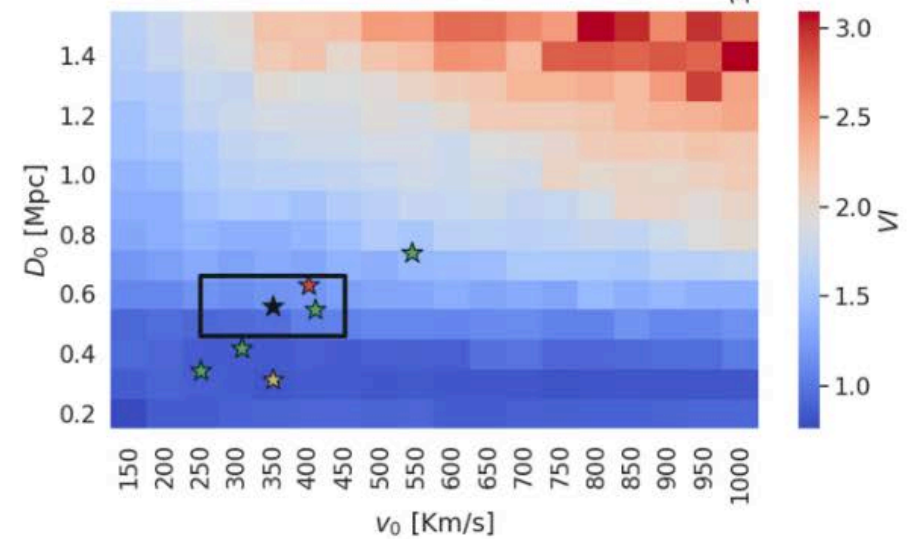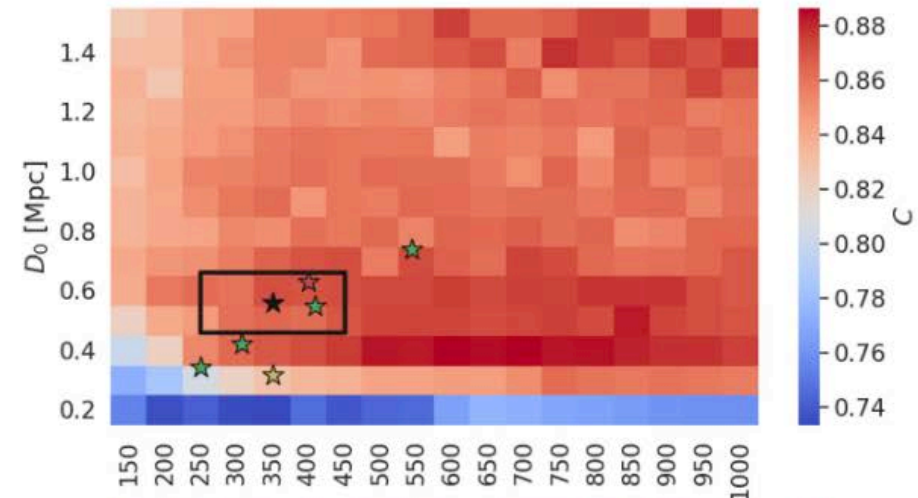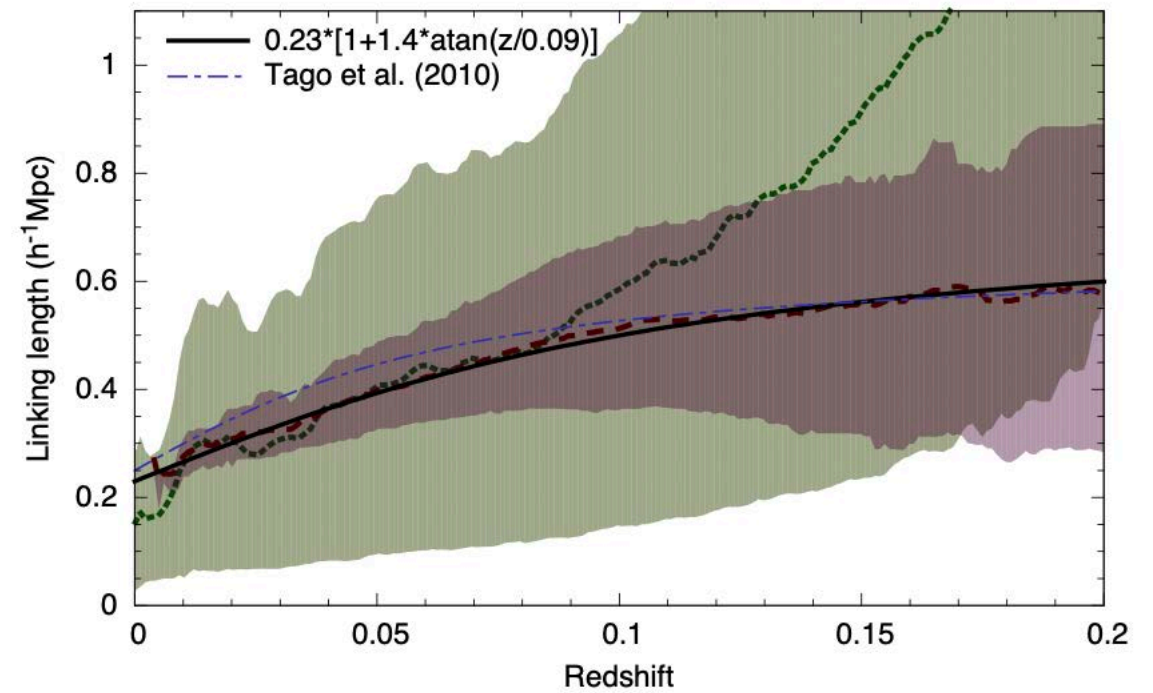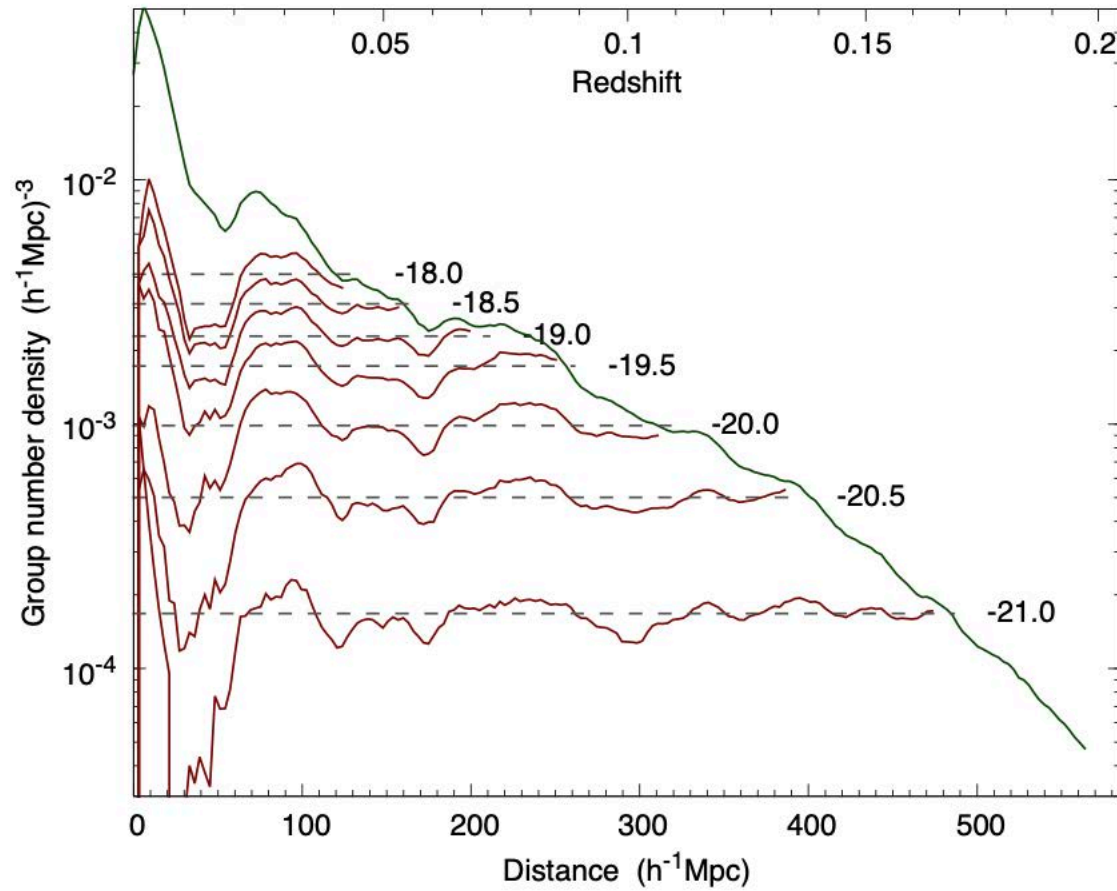
Linking length

Group refinement

- Often merging or closeby groups are taken as one group in FoF

- Multimodality analysis (mclust in R)

- Group membership refinement is based on estimates of the virial radius (in the sky plane) and escape velocity (along the line of sight) of the system.

$$\sigma_v^2 = \frac{1}{(1 + z_{\mathrm{m}})^2(n - 1)} \sum_{i=1}^{n}(v_i - v_{\mathrm{mean}})^2,$$

$$\sigma_{\mathrm{sky}}^2 = \frac{1}{2n(1 + z_{\mathrm{m}})^2} \sum_{i=1}^{n}(r_i)^2,$$

155
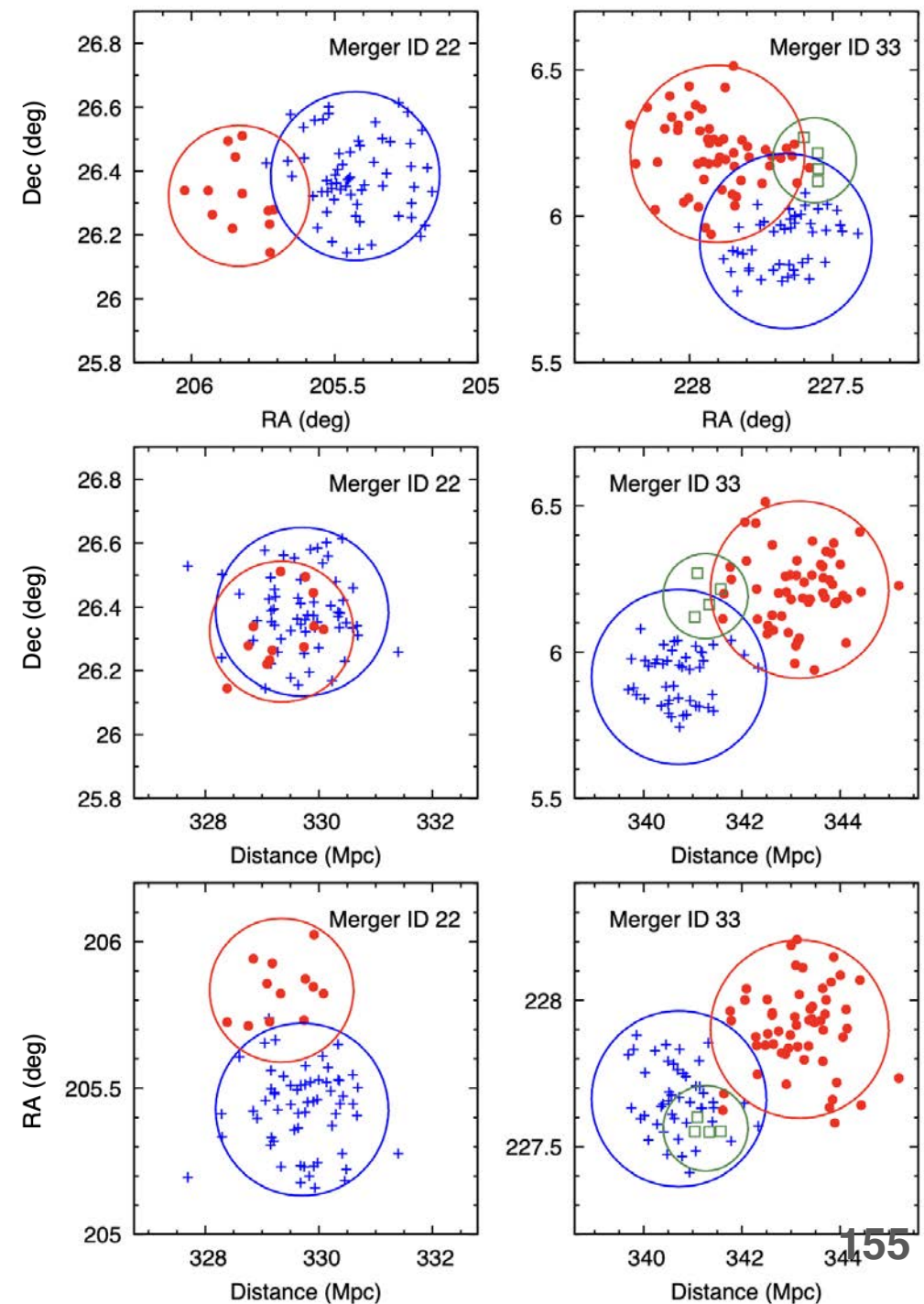
$$d_{\text{gal}} = d_{\text{group}} + \left(d^*_{\text{gal}} - d_{\text{group}}\right) \frac{\sigma_{\text{sky}}}{\sigma_v / H_0},$$

$$d_{\text{gal}} = d_{\text{group}} + \left(d^\star_{\text{gal}} - d_{\text{group}}\right) \frac{d_{LL}(z)}{|v_1 - v_2|/H_0},$$
$$\text{if } |v_1 - v_2|/H_0 > d_{LL}(z).$$

Suppressing FoG effect
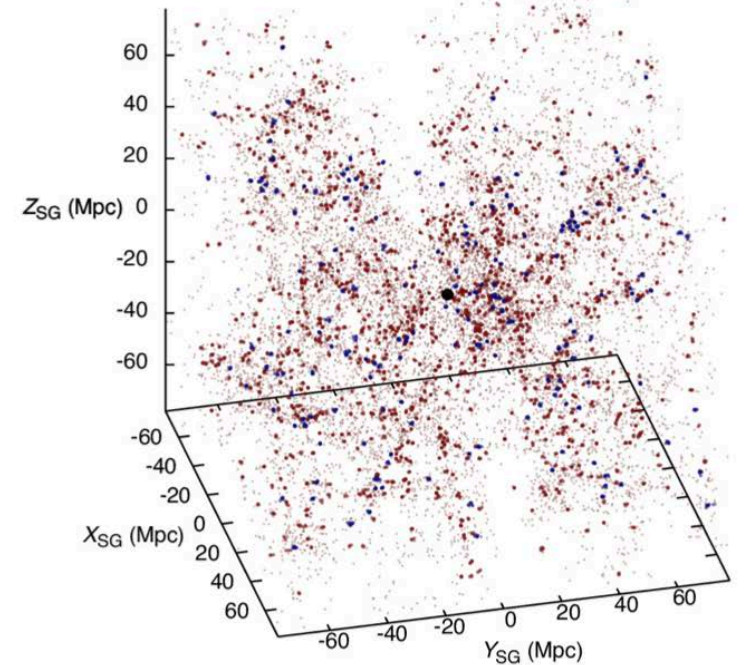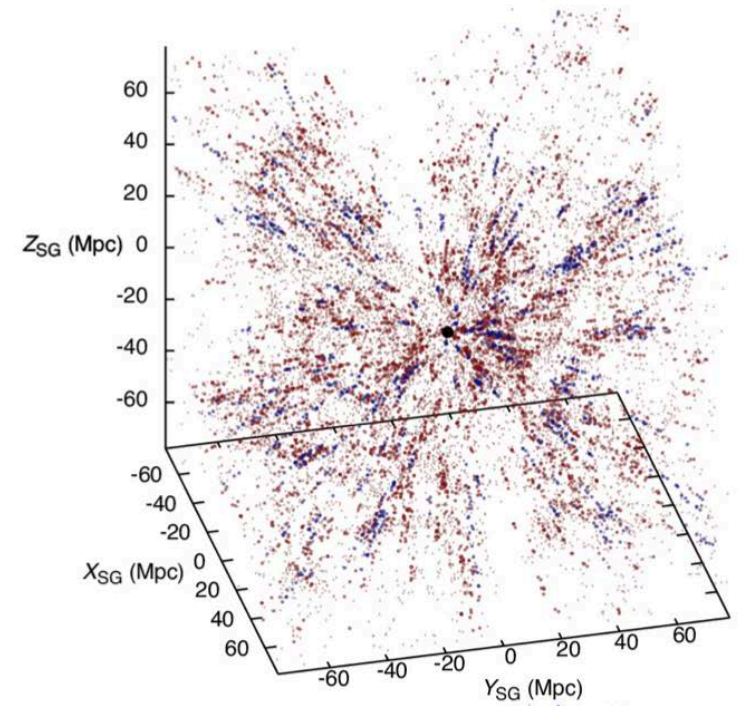
Correction for the redshift space distortions
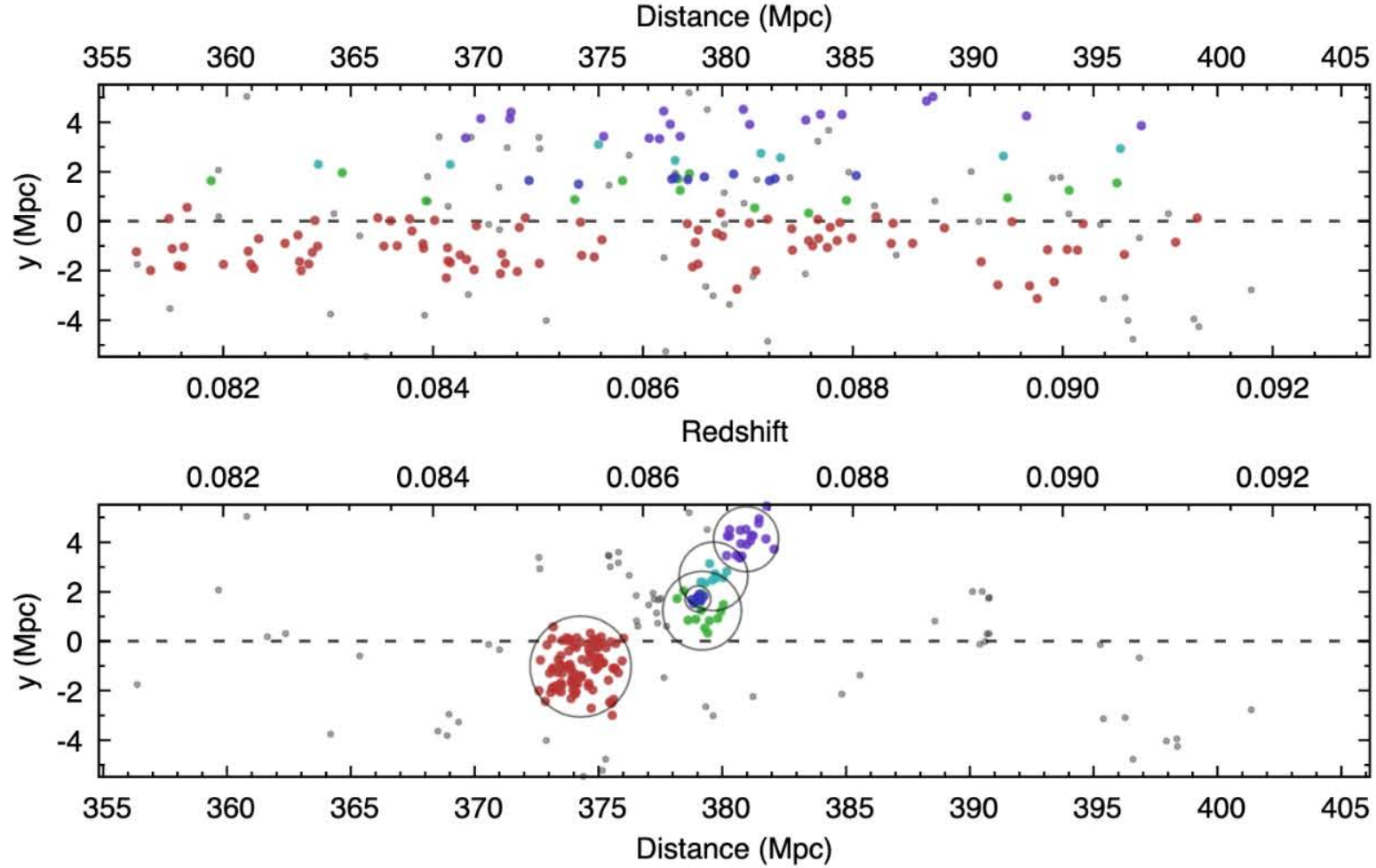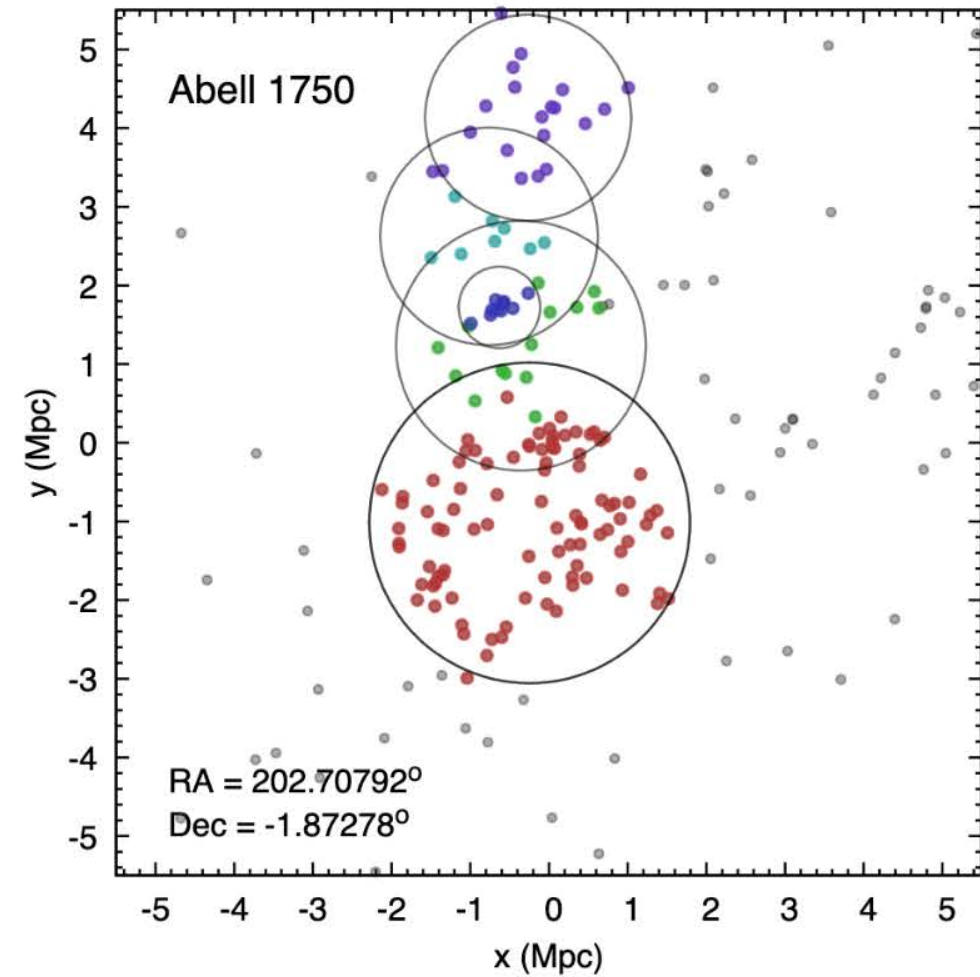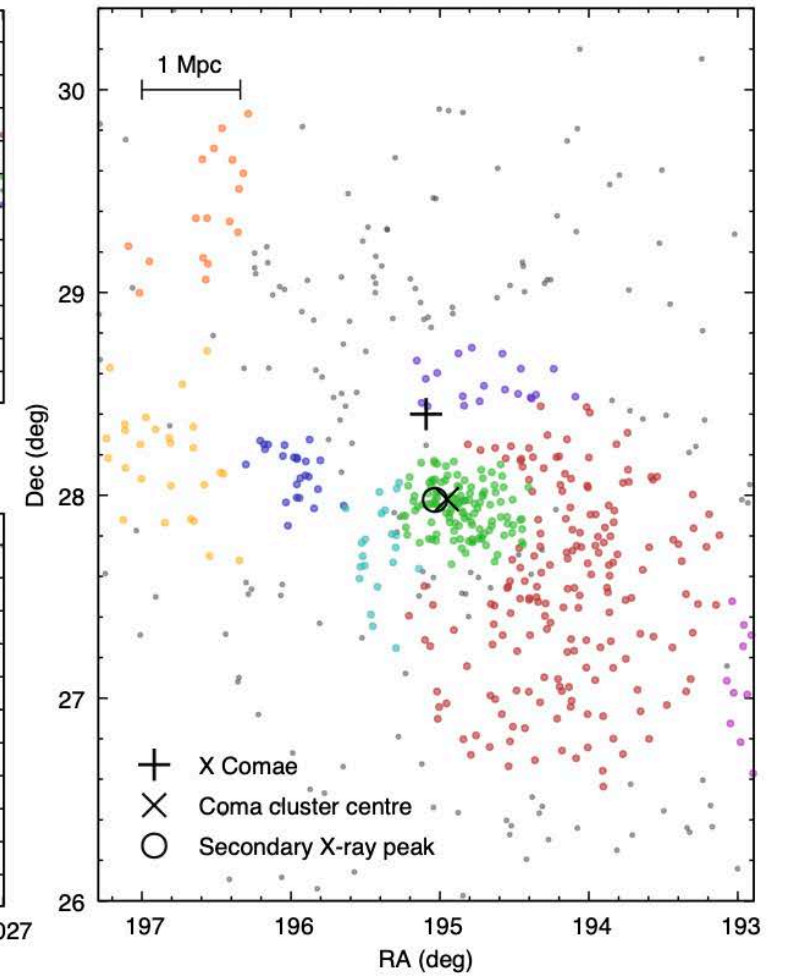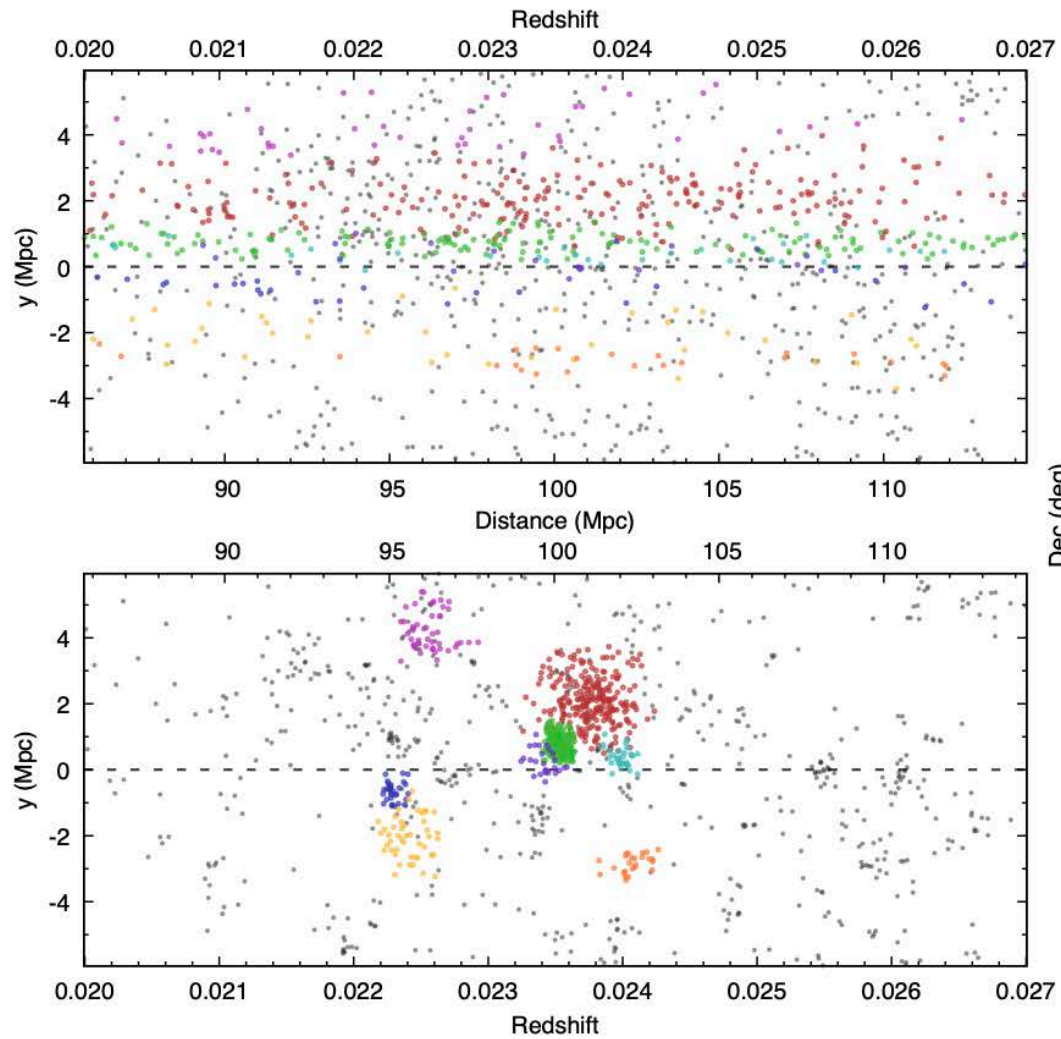
Coma in SDSS

Measuring group properties - centre
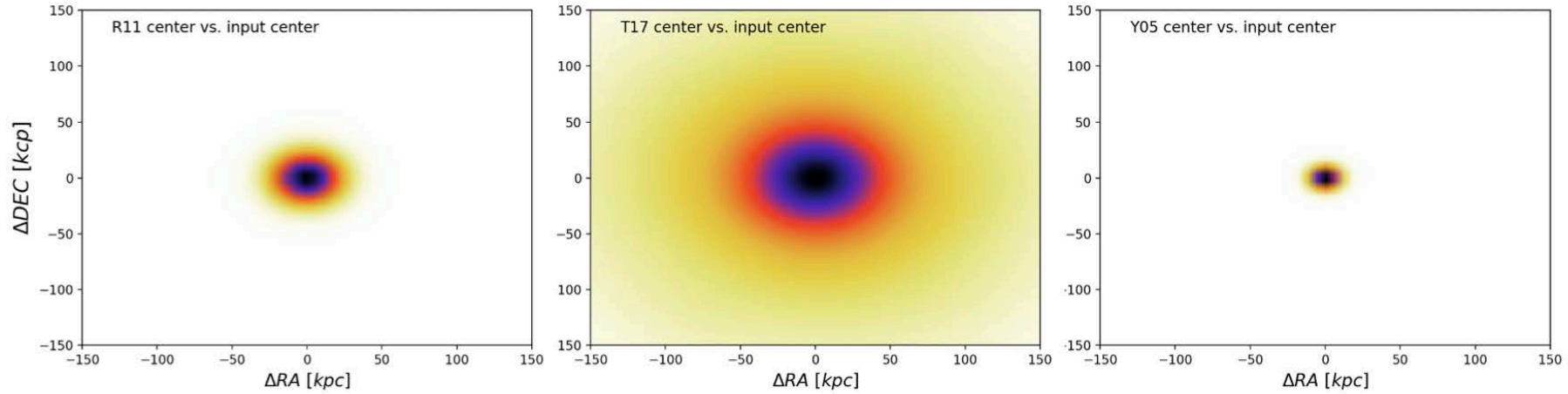
Fig. 6. The figure shows the difference in ΔRA and ΔDEC, estimated in kpc, between the center of the detected optical group and the center of the input halo (left panel), the coordinates of the eSASS X-ray detection and the center of the input halo (central panel), and the center of the detected optical group and of the eSASS X-ray detection.
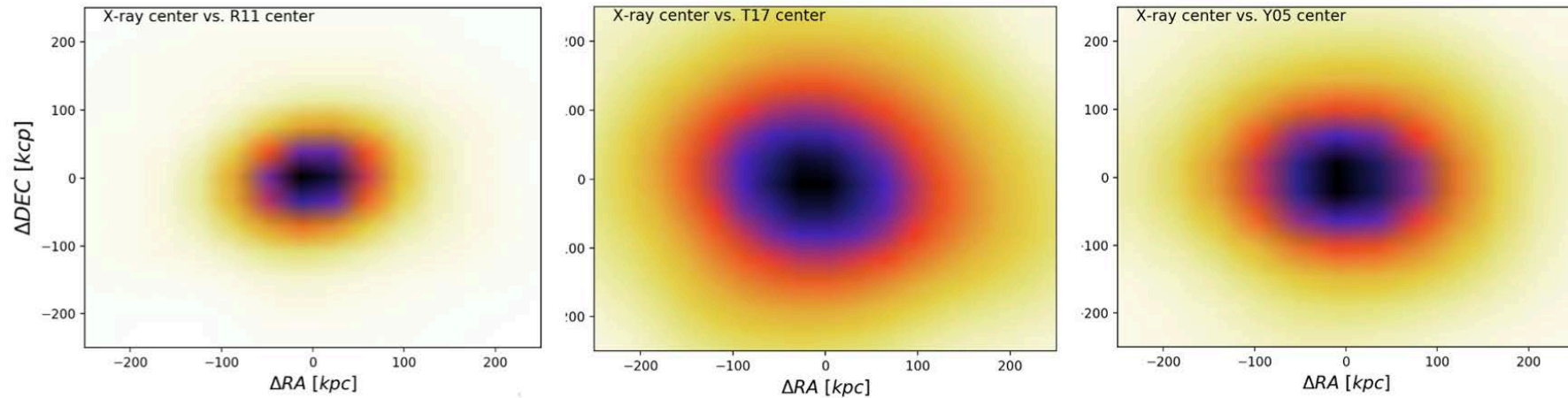
Fig. 7. The figure shows the difference in ΔRA and ΔDEC, estimated in kpc, between the center of the detected optical group and the center of the input halo (left panel), the coordinates of the eSASS X-ray detection and the center of the input halo (central panel), and the center of the detected optical group and of the eSASS X-ray detection.

The Current Group-Finder Pipeline
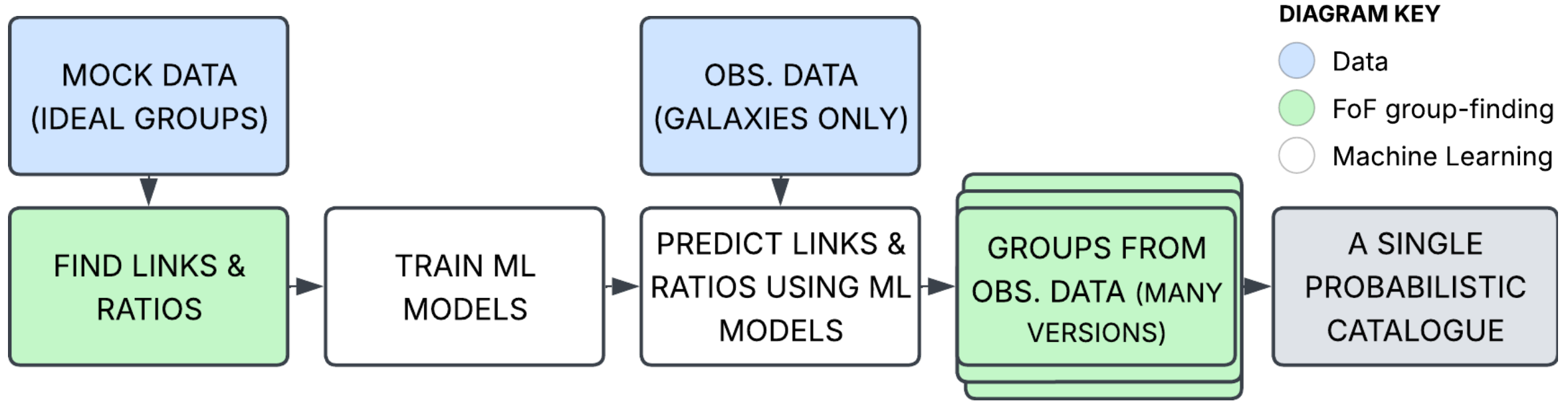
Two components: finding $D_\perp$, R and training ML model

Improvements

Merged groups: refinement part of FoF

Accuracy: unique $D_\perp$, R for all galaxies

Niche: ML component

Universality: optimisable for *almost* any dataset

Output: probabilistic catalogue.. TBD
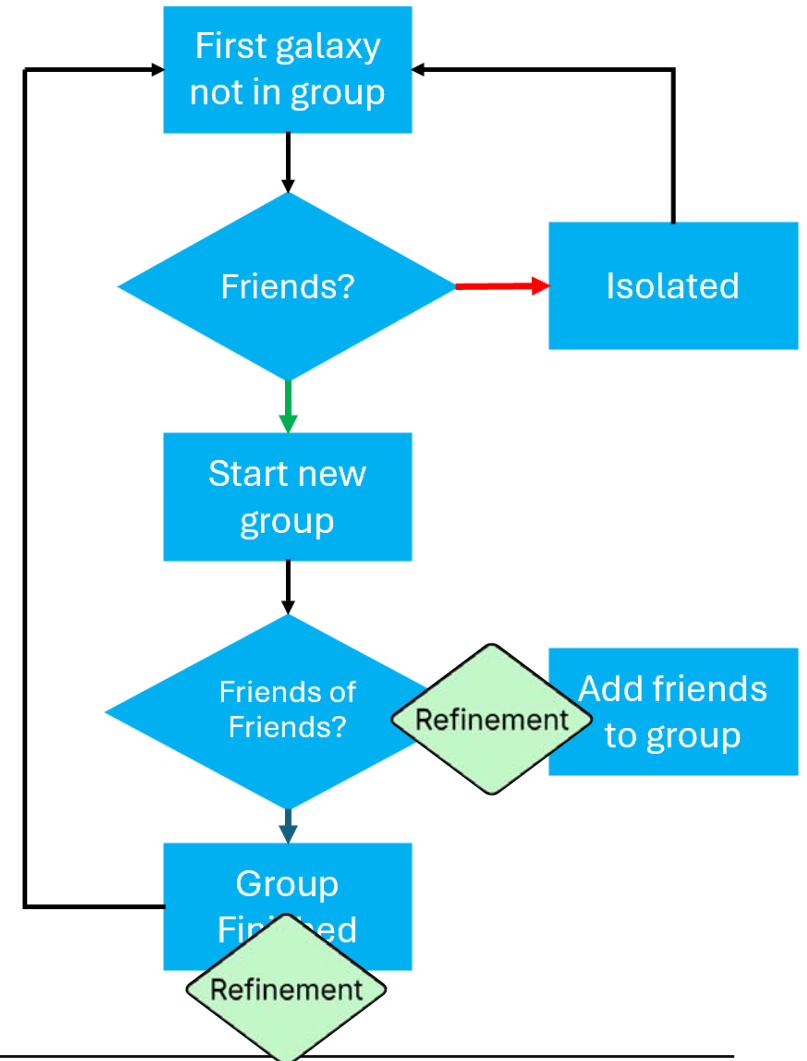
Finding $D_\perp$, R for Mock Groups

FIND LINKS & RATIOS

LINK-RATIO GRID

GET GROUPS FOR EACH POINT IN GRID

GET BEST LINKS-RATIOS FOR EACH GROUP
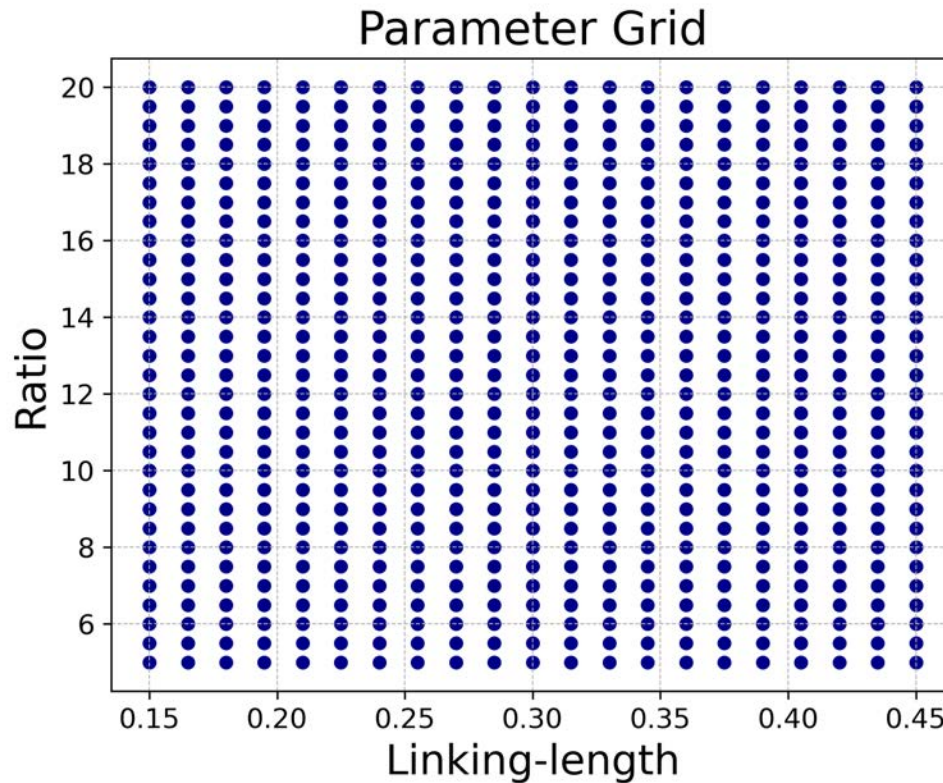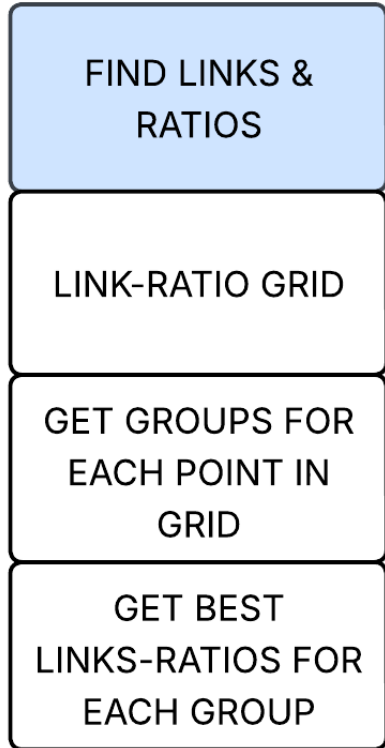
Unique to each group
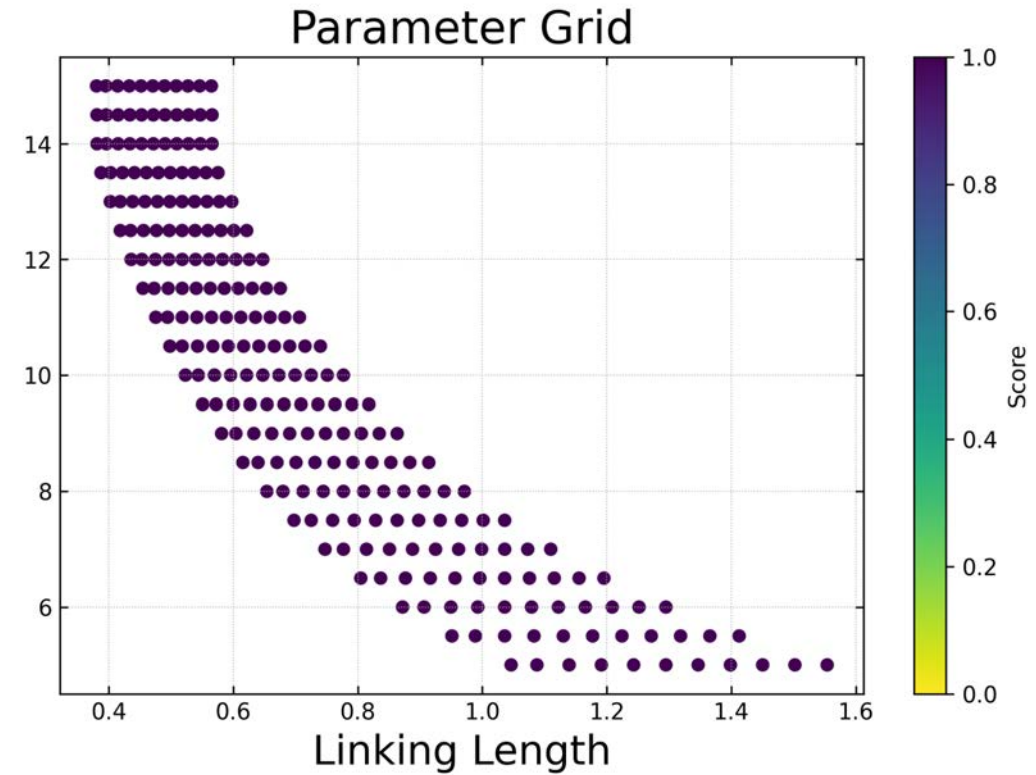
$$\text{Score} = \frac{N_{gal}^2(\text{mock} \cap \text{FoF})}{N_{gal}(\text{mock})\,N_{gal}(\text{FoF})}$$

ML Model

Training (XGBRegressor)

Inputs: Group mass, Ngal, Z, mag

Outputs: $D_\perp$, R

Predicting

$D_\perp$, R for a wide range of possible

Ngal & group masses
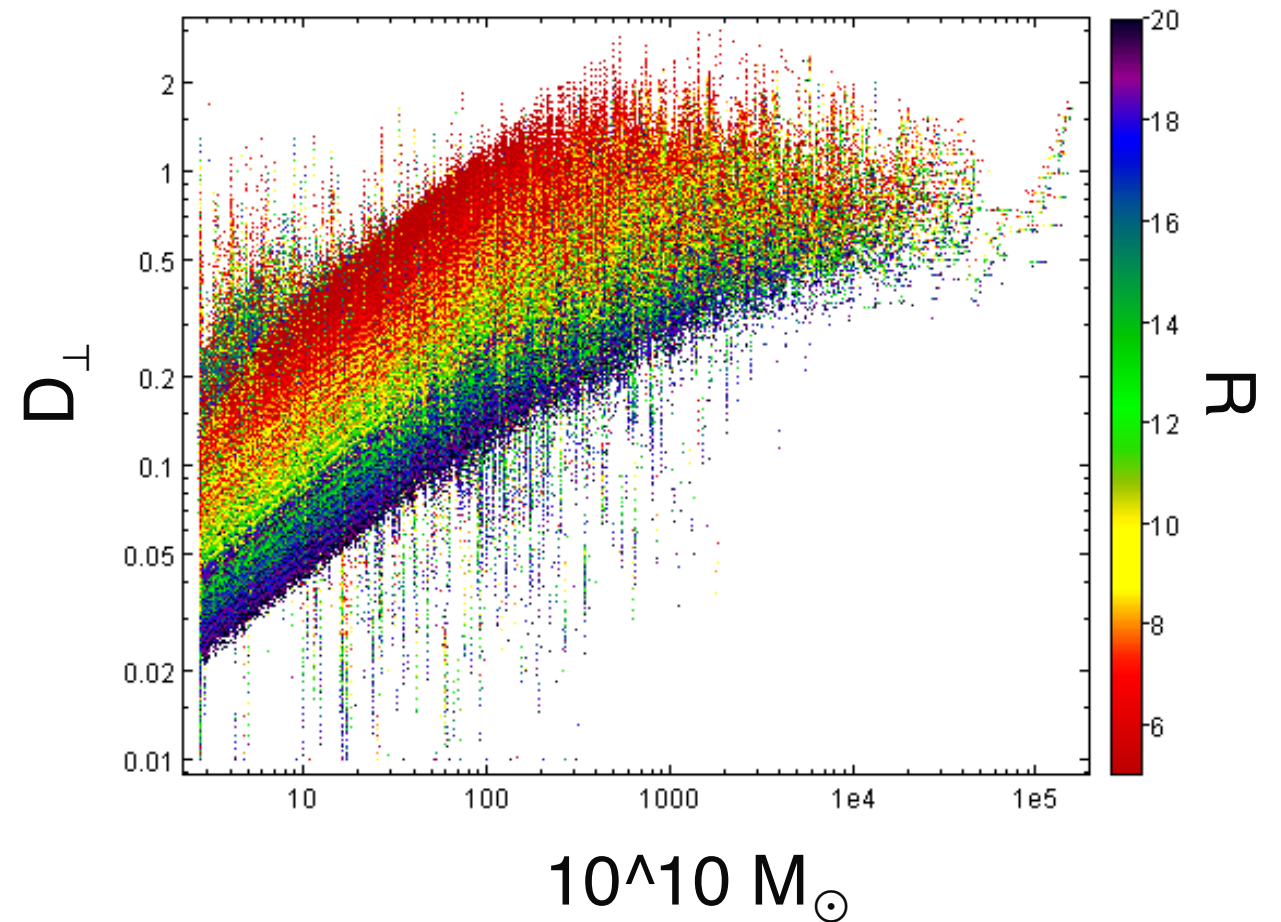
Mass Estimation Inside FoF
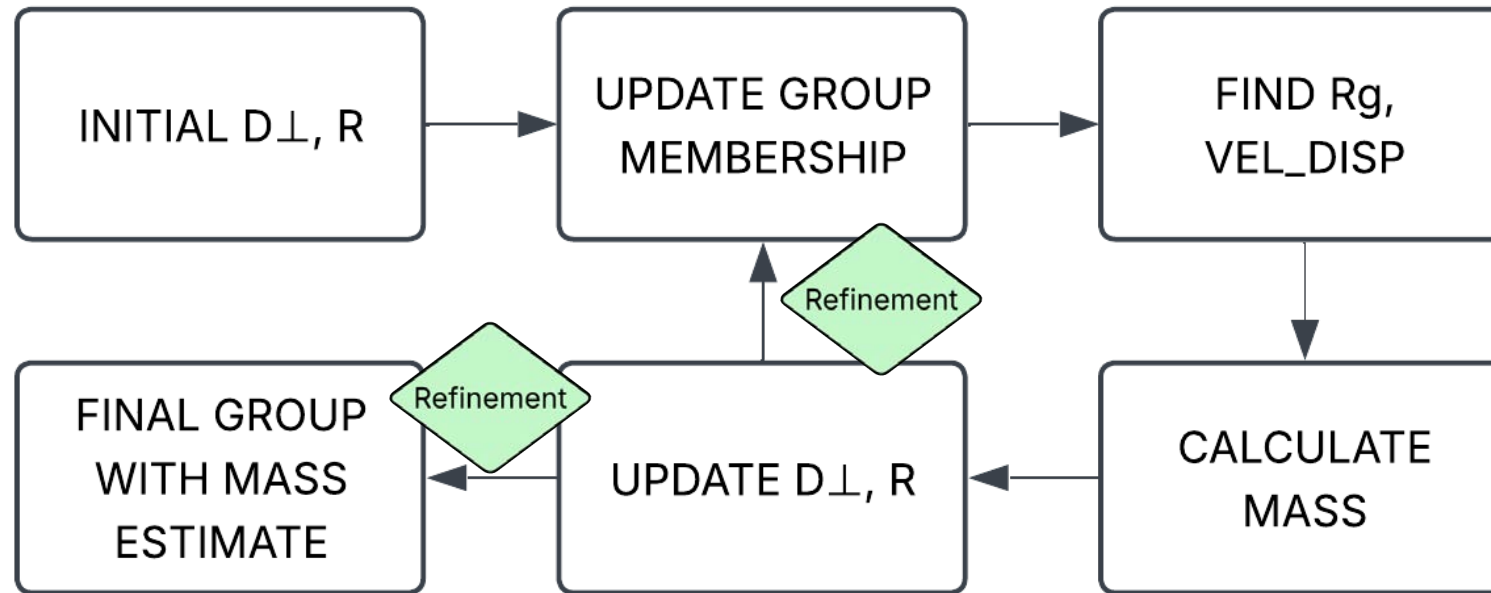
Dynamical mass

$$M_{tot} = 2.325 \times 10^{12} \frac{R_g}{\text{Mpc}} \left(\frac{\sigma_v}{100 \text{ km} s^{-1}} \right)^2 M_\odot$$

Depth 60 - 80 Mpc
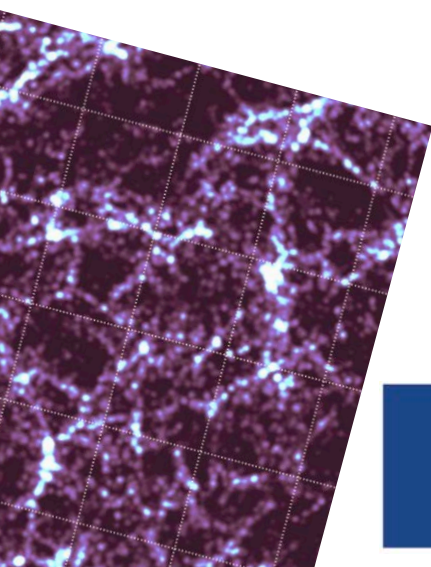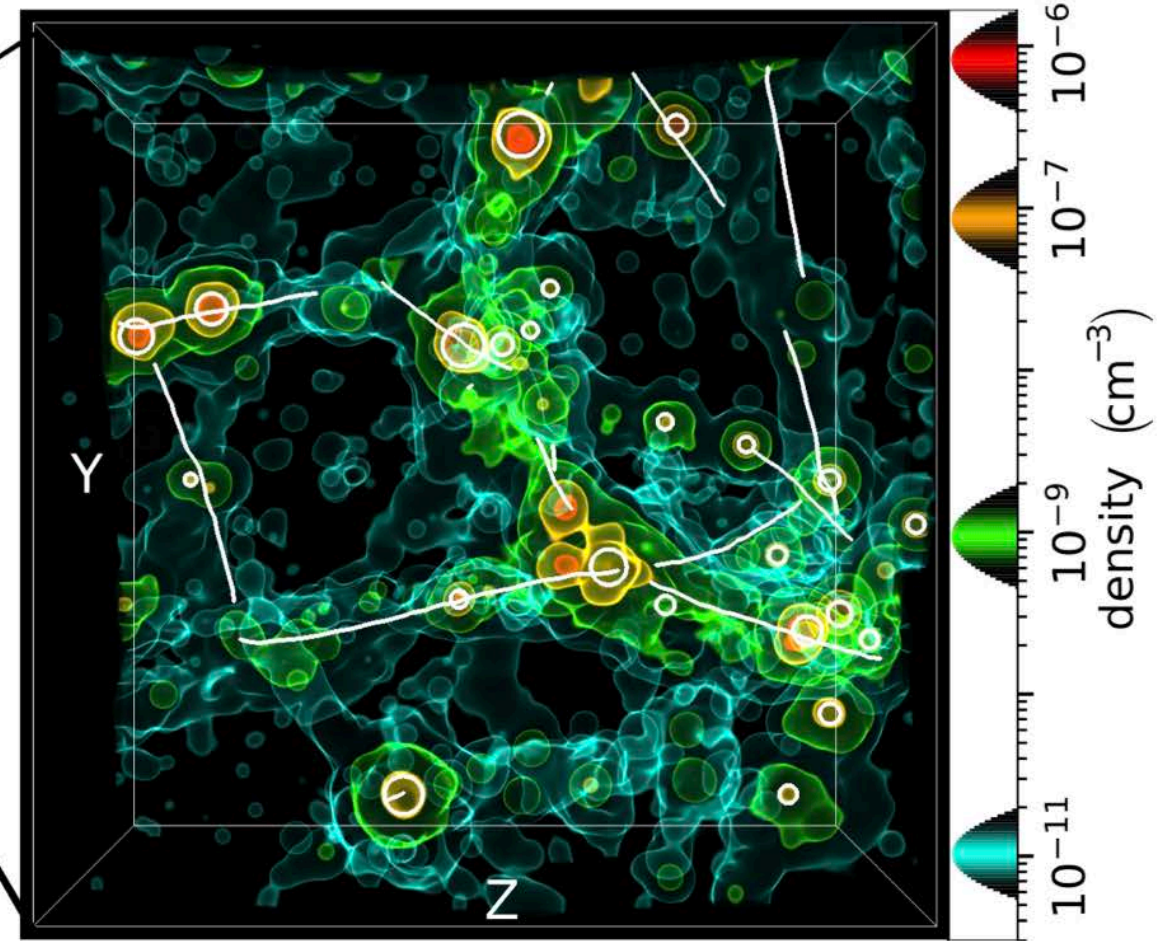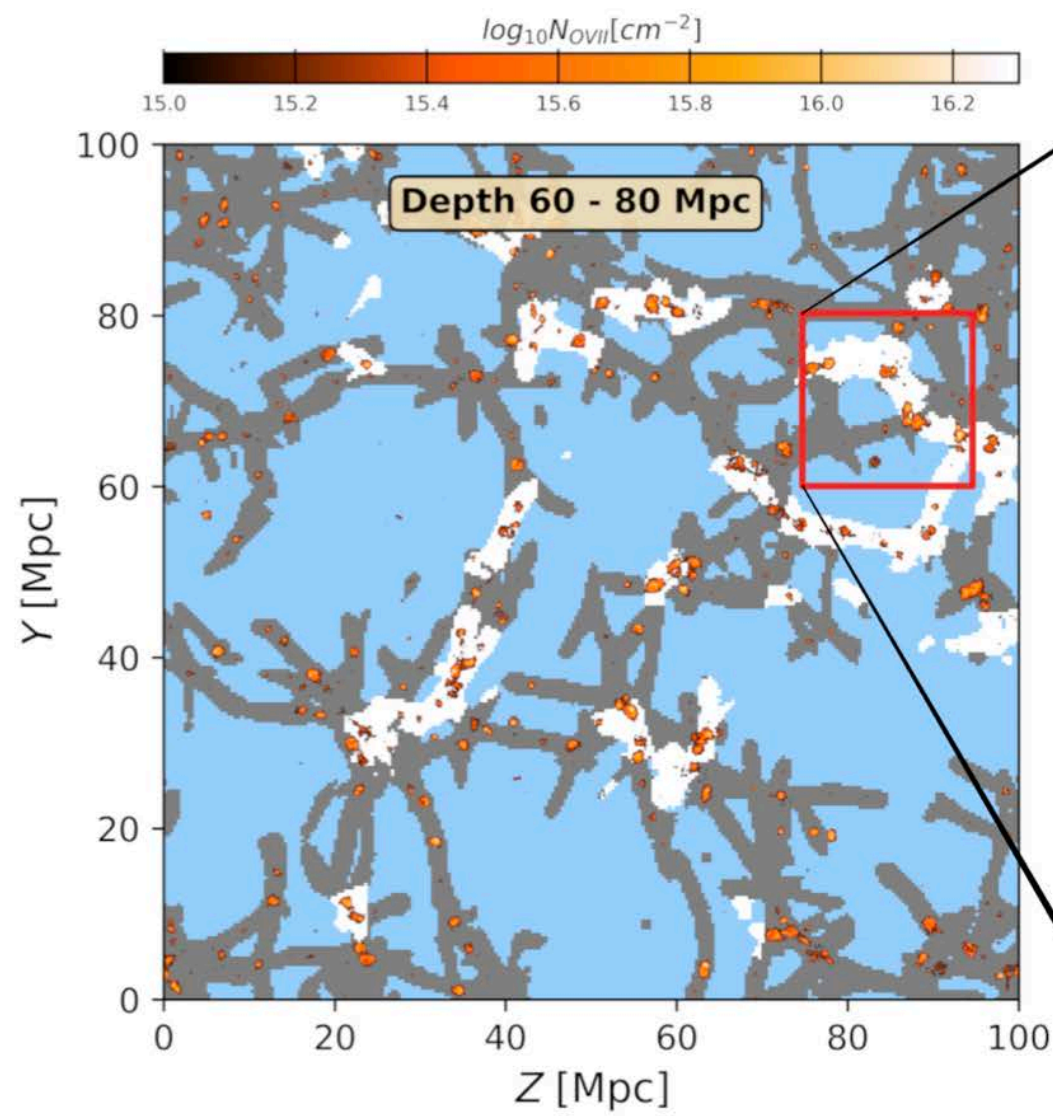
Hunting for WHIM (warm hot intergalactic medium)
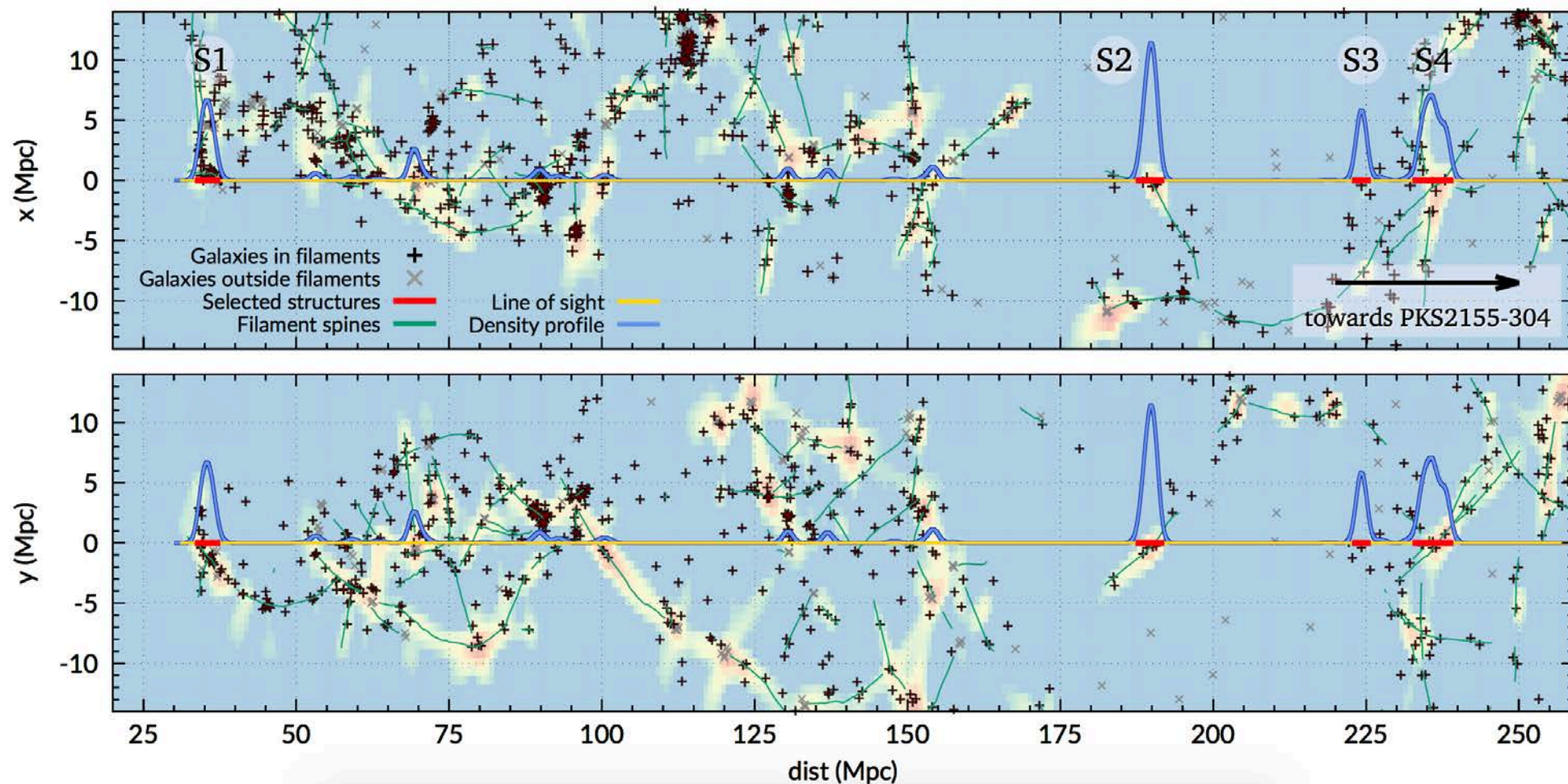
Why do we care about the cosmic web?

Galaxy filaments

Marked point process for filamentary network detection

Tempel et al. (2014, 2016)

Filaments in the SDSS

Marked point process
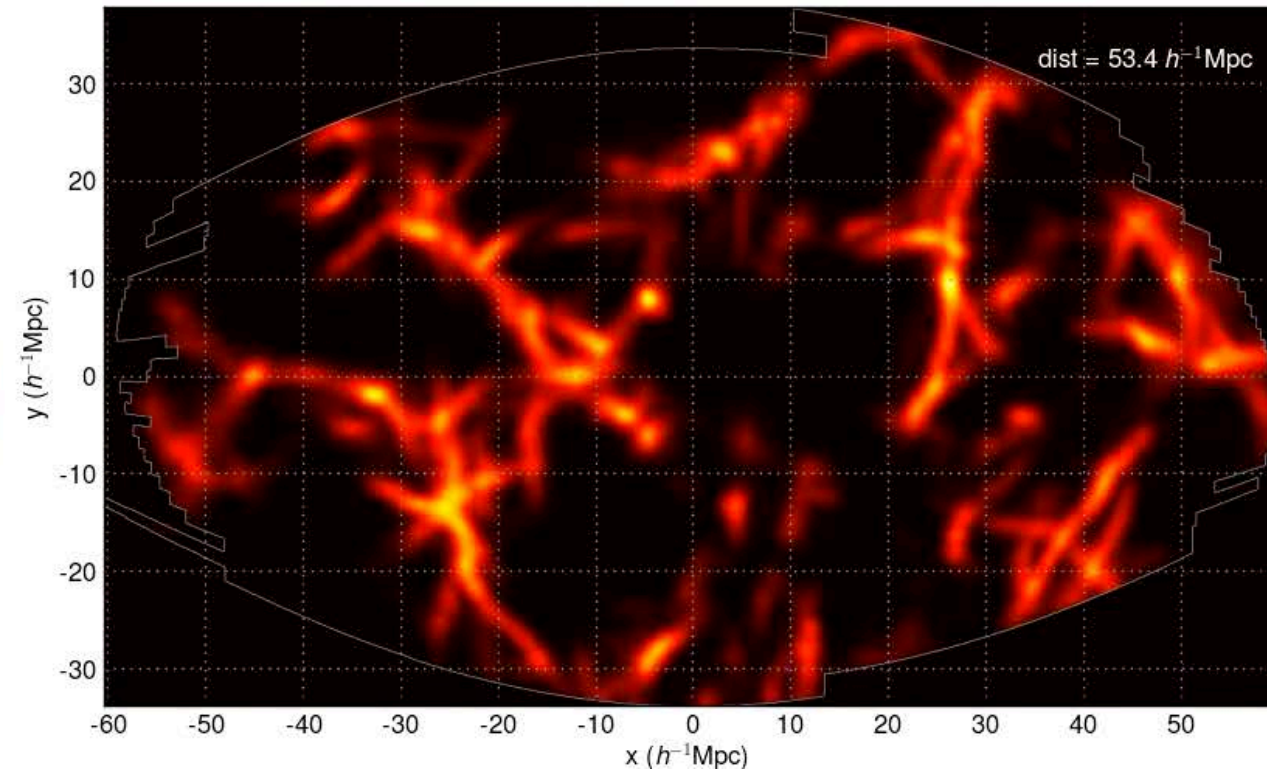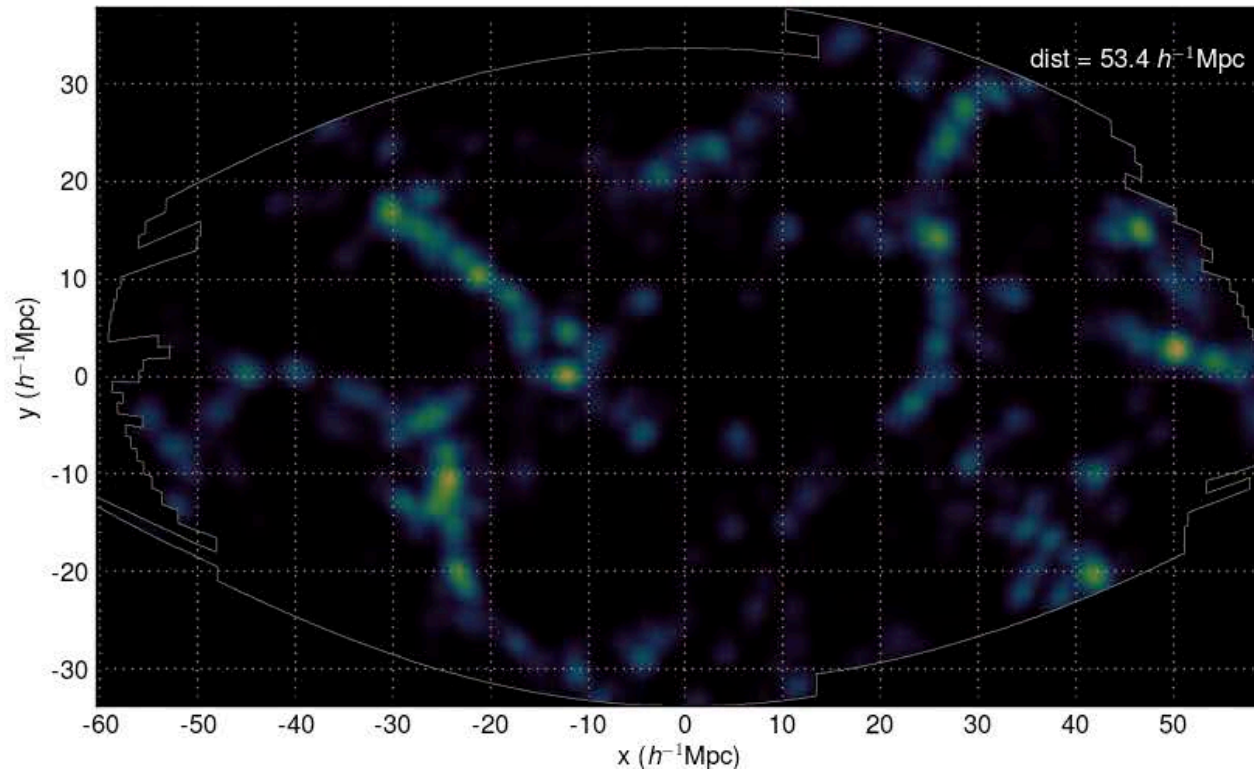
— Extracted filaments
— Connected cylinders
● Galaxies
● Galaxies in groups
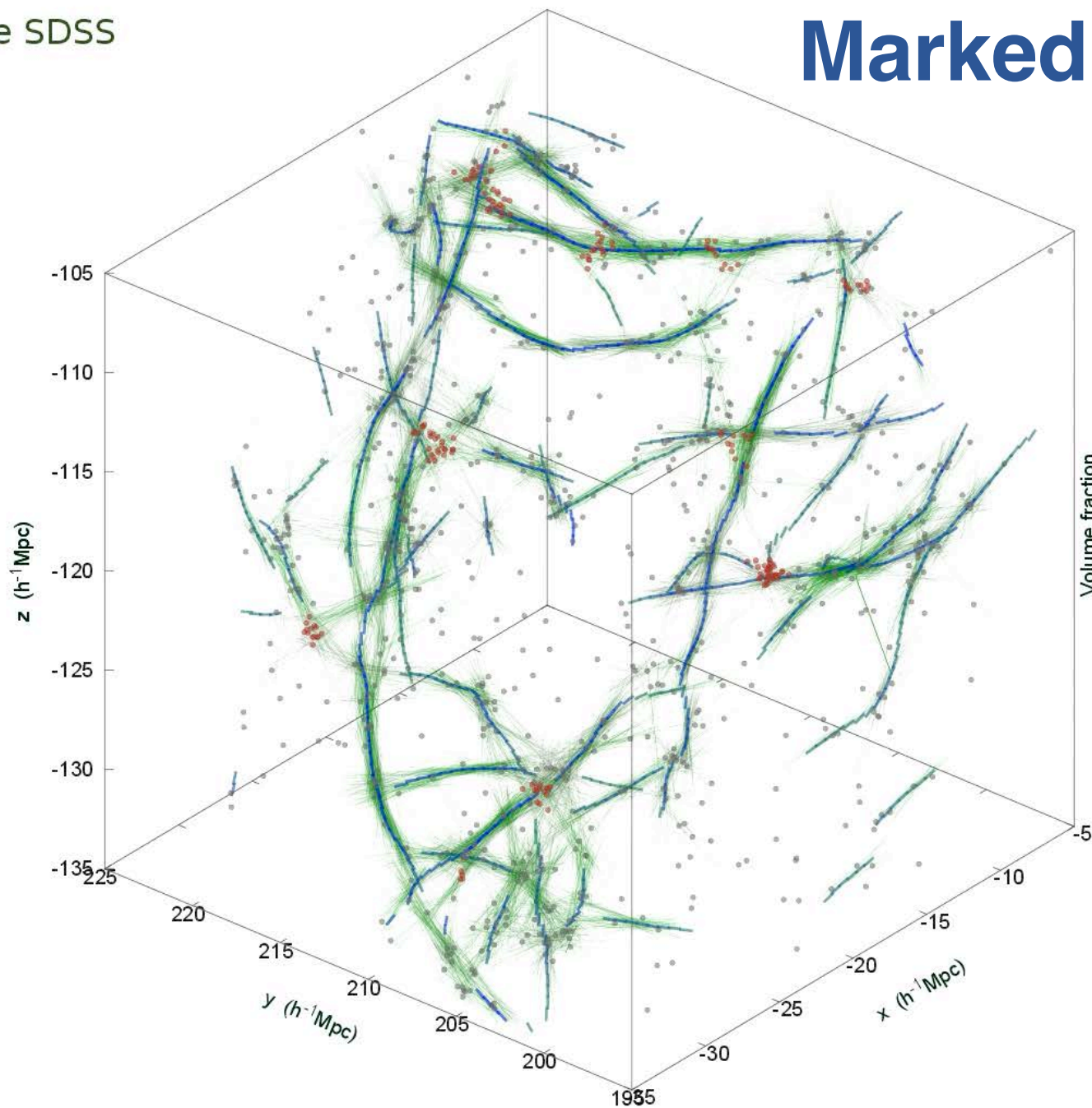
Filament length distribution:
whole SDSS volume
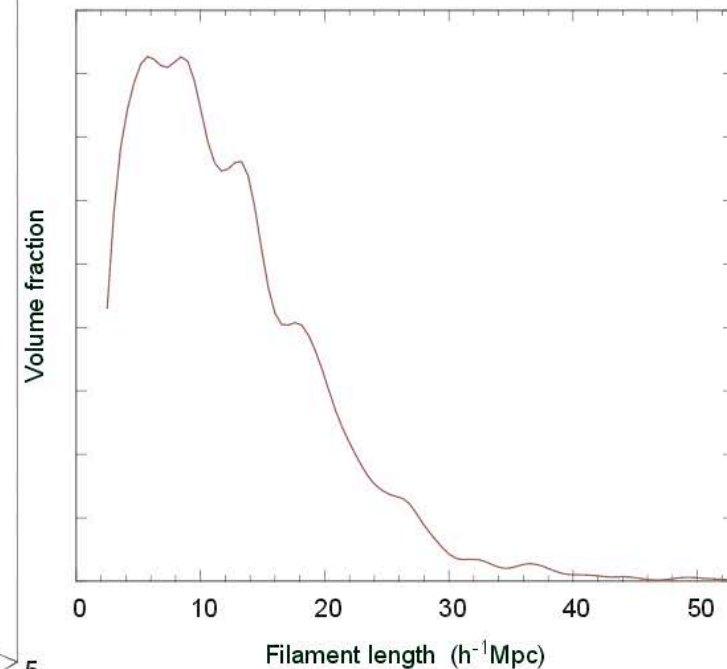
- The key idea is to see the filamentary network as an   object point process.

- 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, it's shadow and attraction regions depend on the model.
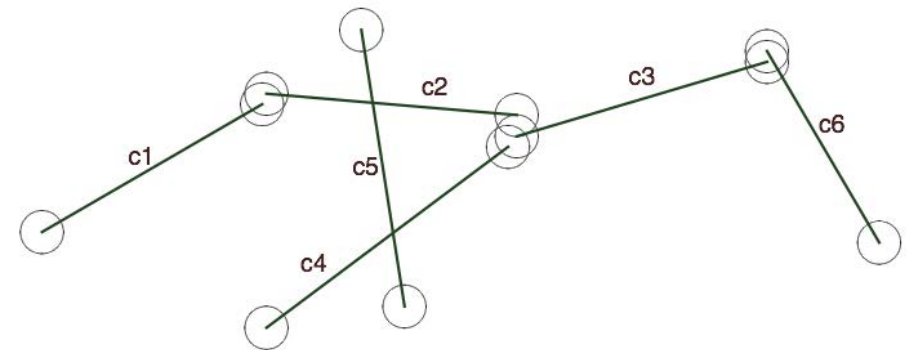
Figure 2. Two dimensional representation of cylinder configuration: attraction regions are shown with spheres. In this configu-

Stoica et al. (2003, 2005)
Stoica, Martinez, Saar (2007, 2010)
Tempel et al. (2014, 2016)

TARTU OBSERVATORY
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Probability density that depends on the underlying data (position of galaxies) and the detected network (filamentary pattern)

Bisous model (Candy model)

The probability density for a marked point process based on random cylinders can be written

$$p(\boldsymbol{y}|\theta) = \frac{\exp\left[-U(\boldsymbol{y}|\theta)\right]}{\alpha} \qquad (4)$$

where α is the normalising constant, θ is the vector of the model parameters and $U(\boldsymbol{y}|\theta)$ is the energy function of the system. Here, $\boldsymbol{y}$ is the configuration of cylinders.

Following these two ideas the energy function given by (4) can be specified as:

$$U(\boldsymbol{y}|\theta) = U_{\mathrm{d}}(\boldsymbol{y}|\theta) + U_{\mathrm{i}}(\boldsymbol{y}|\theta), \qquad (5)$$

where $U_{\mathrm{d}}(\boldsymbol{y}|\theta)$ is the data energy (see Sect. 3.4) and $U_{\mathrm{i}}(\boldsymbol{y}|\theta)$ is the interaction energy (see Sect. 3.5) associated to the first and second assumptions above, respectively. In fact, it is perfectly reasonable to think that the data energy is the reason that the cylinders in the galaxy field are positioned just so, and that the interaction energy is the main factor which causes the cylinders to form filamentary patterns.

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Metropolis–Hastings algorithm to sample
from probability density:

$$p(\boldsymbol{y}|\theta) = \frac{\exp\left[-U(\boldsymbol{y}|\theta)\right]}{\alpha}$$

- birth (uniform, connected)

$$\min\left\{1, \frac{p_d}{p_b} \frac{d(\mathbf{y} \cup \{\zeta\}, \zeta)}{b(\mathbf{y}, \zeta)} \frac{p_n(\mathbf{y} \cup \{\zeta\})}{p_n(\mathbf{y})}\right\}$$

- death

$$b(\mathbf{y}, \zeta) = \frac{p_1}{v(K)} + p_2 b_a(\mathbf{y}, \zeta)$$

- change

Simulated annealing:

$$p_n(\mathbf{y}) \propto [p(\mathbf{y})]^{\frac{1}{T_n}}$$
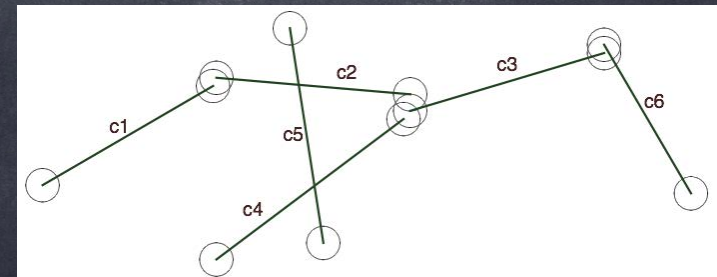
$$T_n = \frac{1}{\log(n+1)}$$

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

Bisous model

Data energy:

$$U_d(\boldsymbol{x}|\theta) = -\sum_{x \in \boldsymbol{x}} \left[\log(p_{vu}(x)p_{vh}(x)) - \sigma^2(x) \right], \qquad (27)$$

Hypothesis testing to test the "uniformity" of a filament and to test the "locally high density" in a filament.

$$p_{vu} = \boldsymbol{P}[X|X + \tilde{X}, p(\rho_u)] \leqslant \alpha_u, \qquad (21)$$

$$p_{vh} = \boldsymbol{P}[X|X + \tilde{X}, p(\rho_h)] \leqslant 1 - \alpha_h. \qquad (24)$$

Cylinder concentration:

$$\sigma^2 = \frac{1}{n-2} \sum_{j=1}^{n} d_j^2, \qquad (25)$$
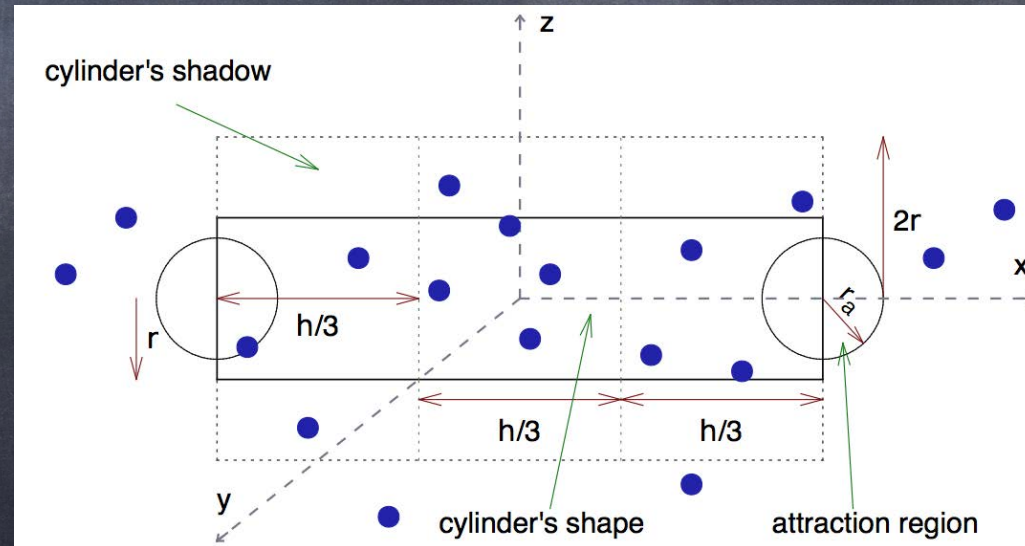
Bisous model

Interaction energy:

Repulsive cylinders,
0,1,2-connected cylinders
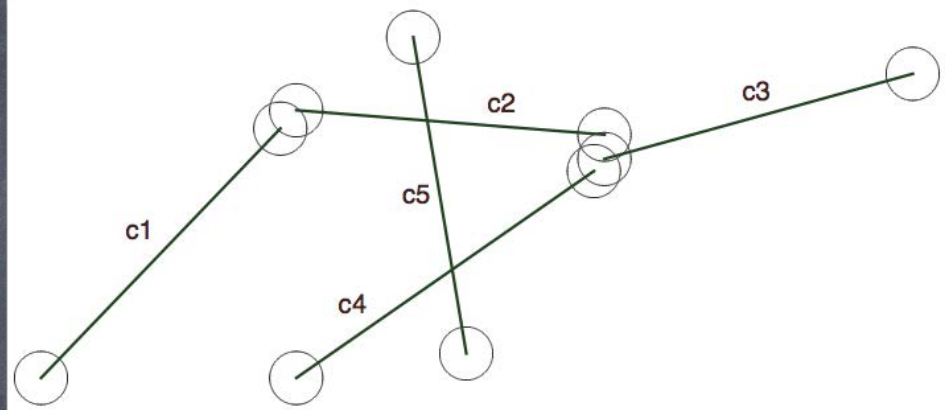
$$U_i(\boldsymbol{y}|\theta) = -n_k(\boldsymbol{y}) \log \gamma_k - \sum_{2=0}^{2} n_s(\boldsymbol{y}) \log \gamma_s, \qquad (29)$$

Data energy:

Tempel et al. 2014
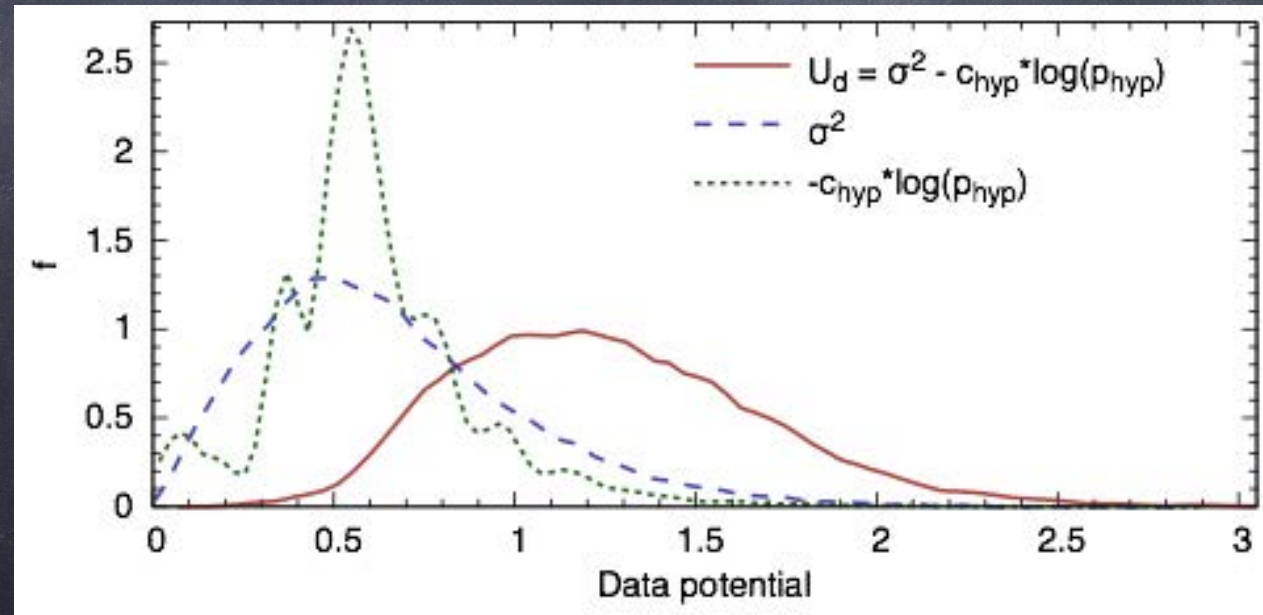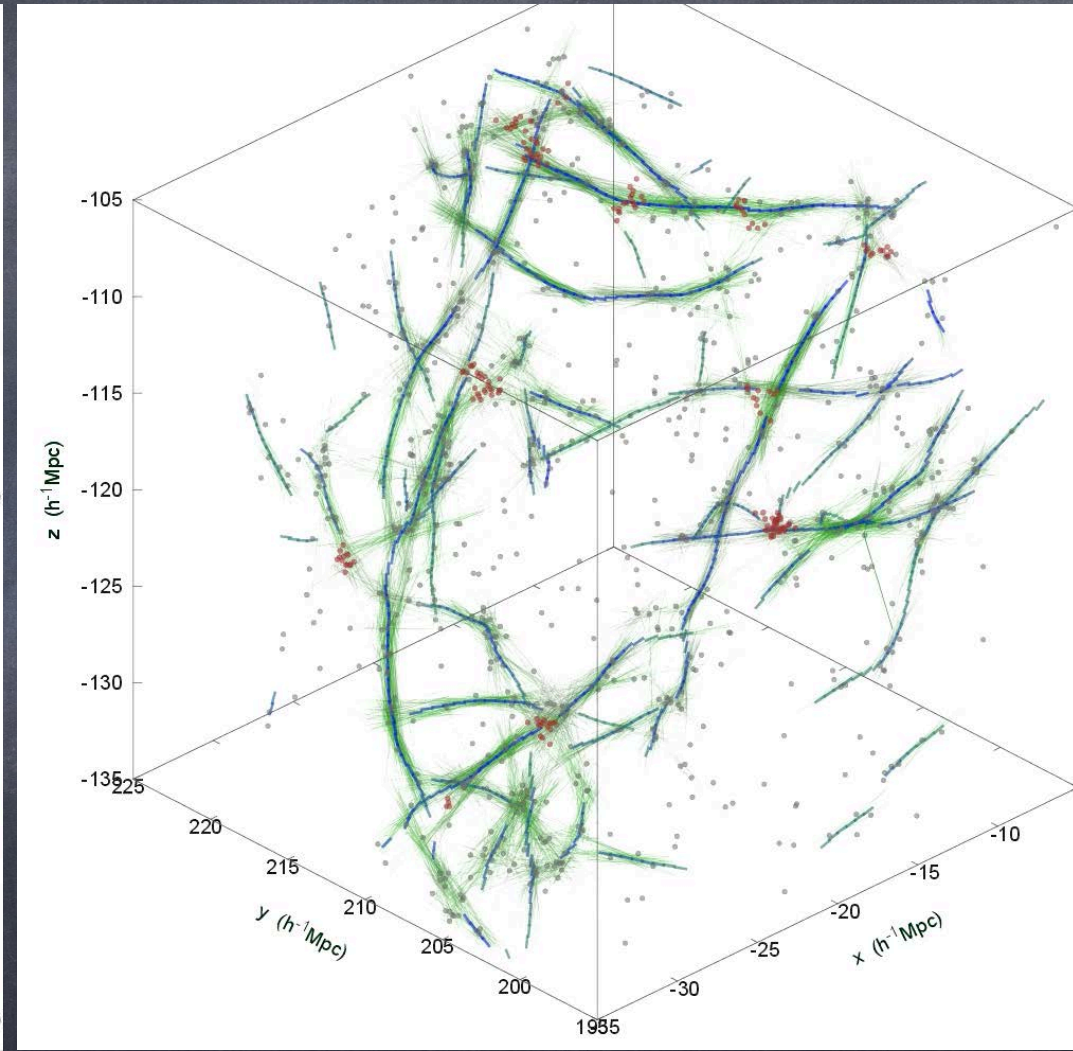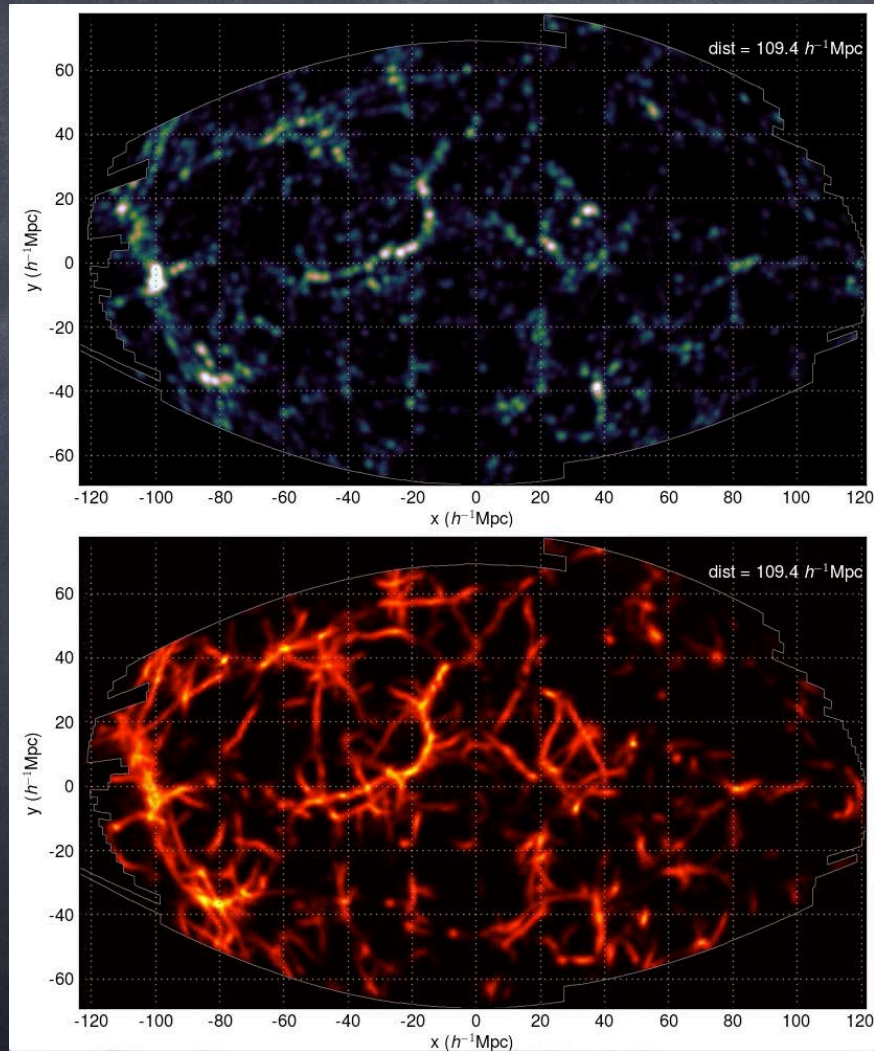
Extracting single filaments

- Set of simulations (50 simulations): 100000x200000 moves!

- 50x30 = 1500 realizations

⬇

- Density field of filaments

- Orientation field of filaments

⬇

Single filaments
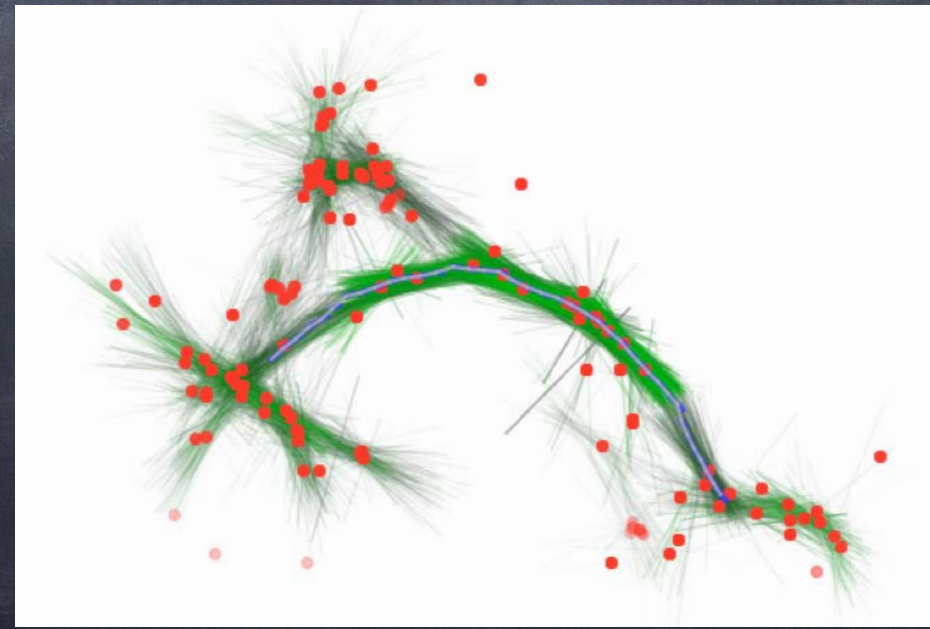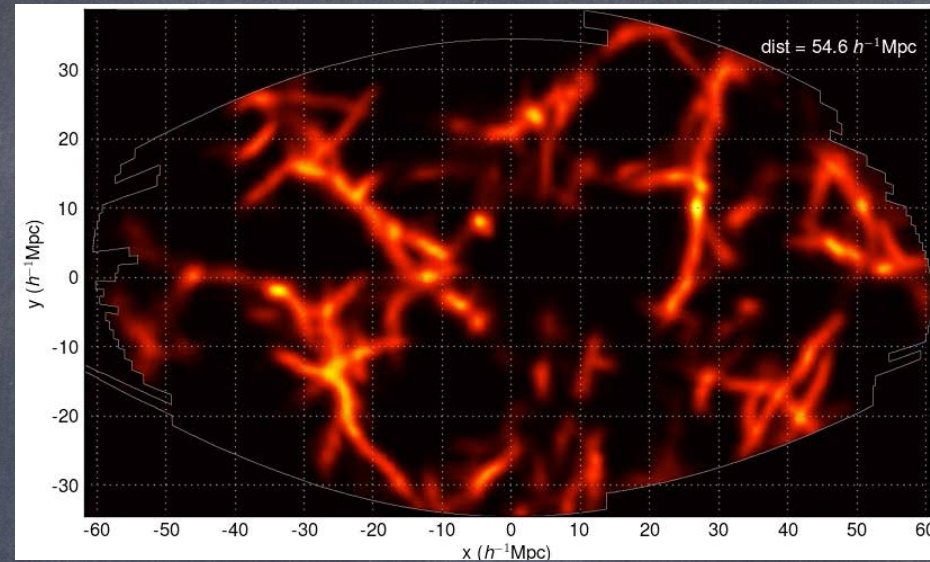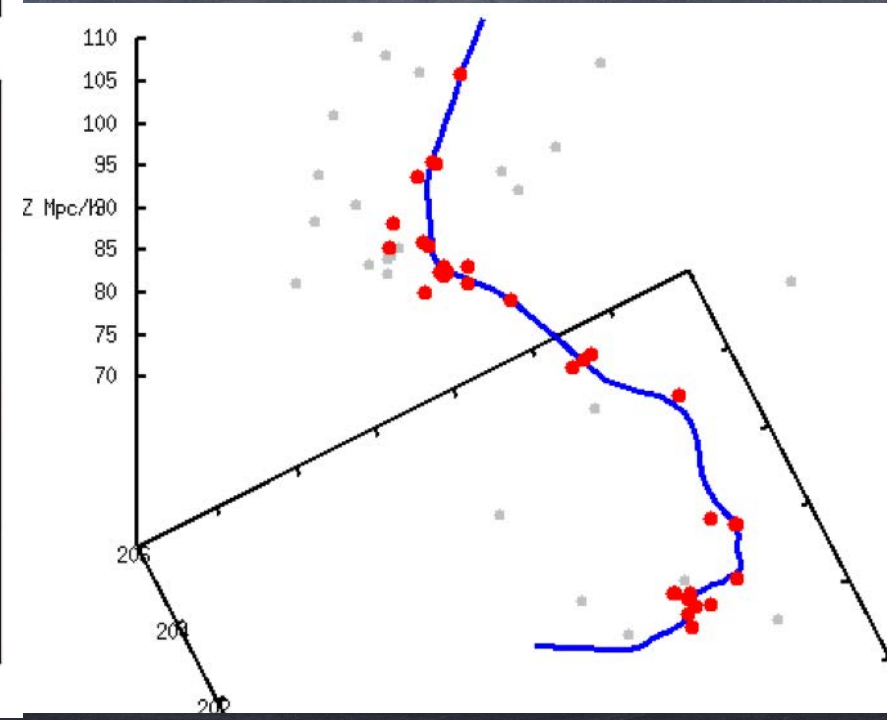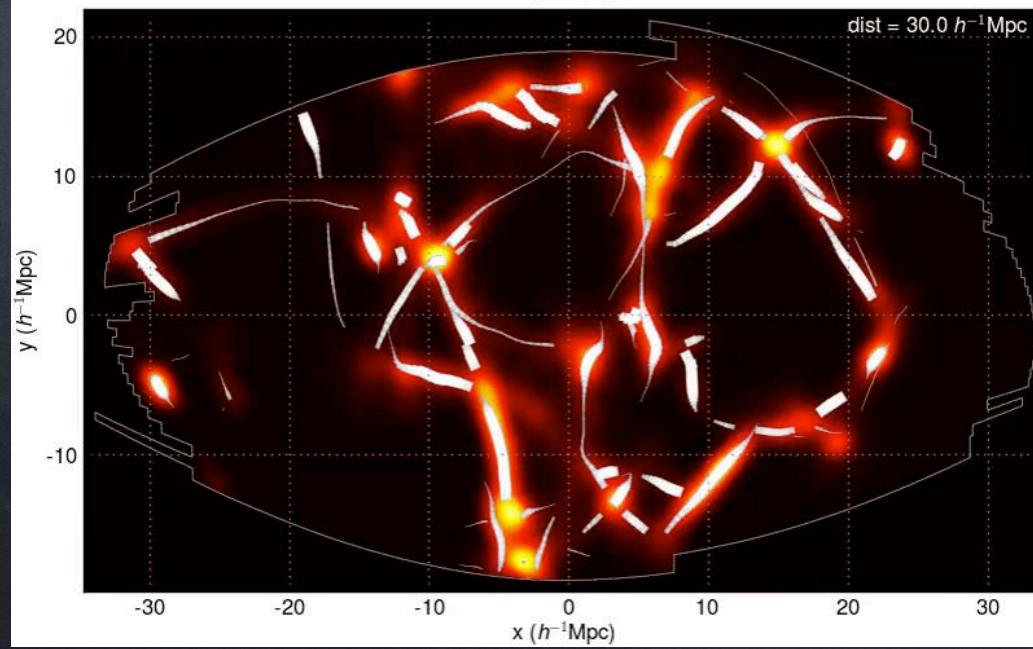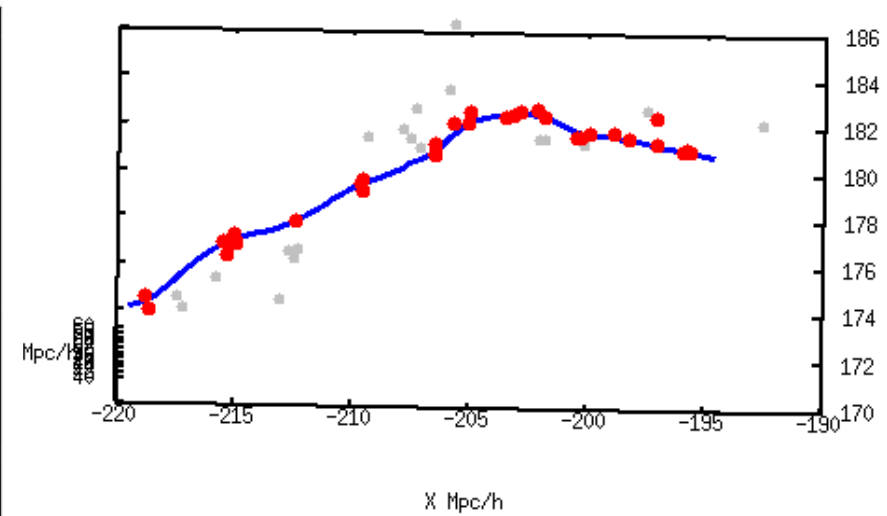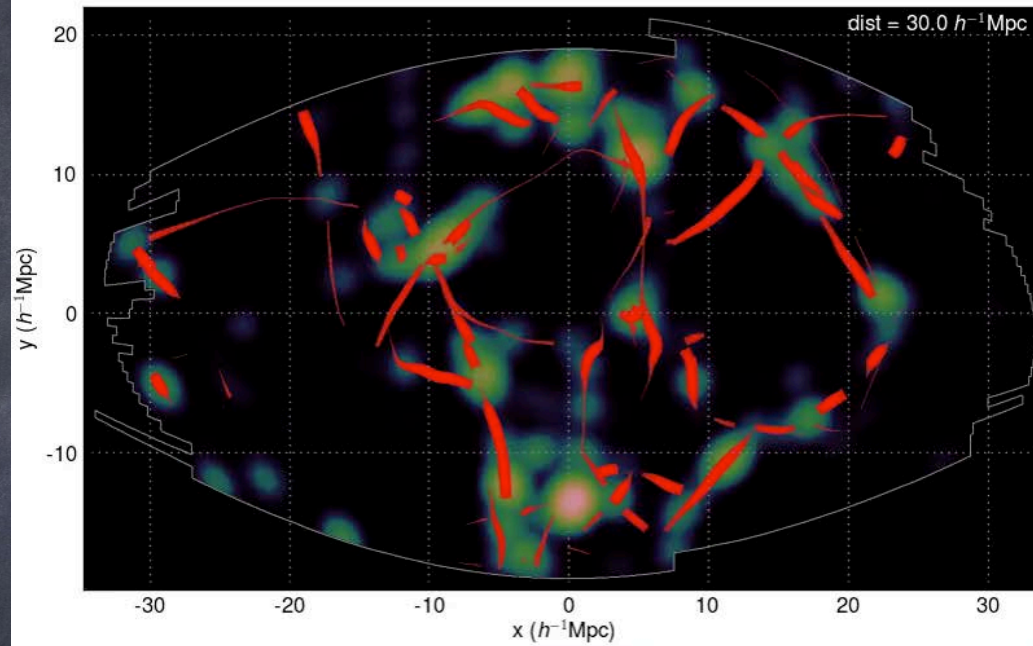
Detected filamentary pattern
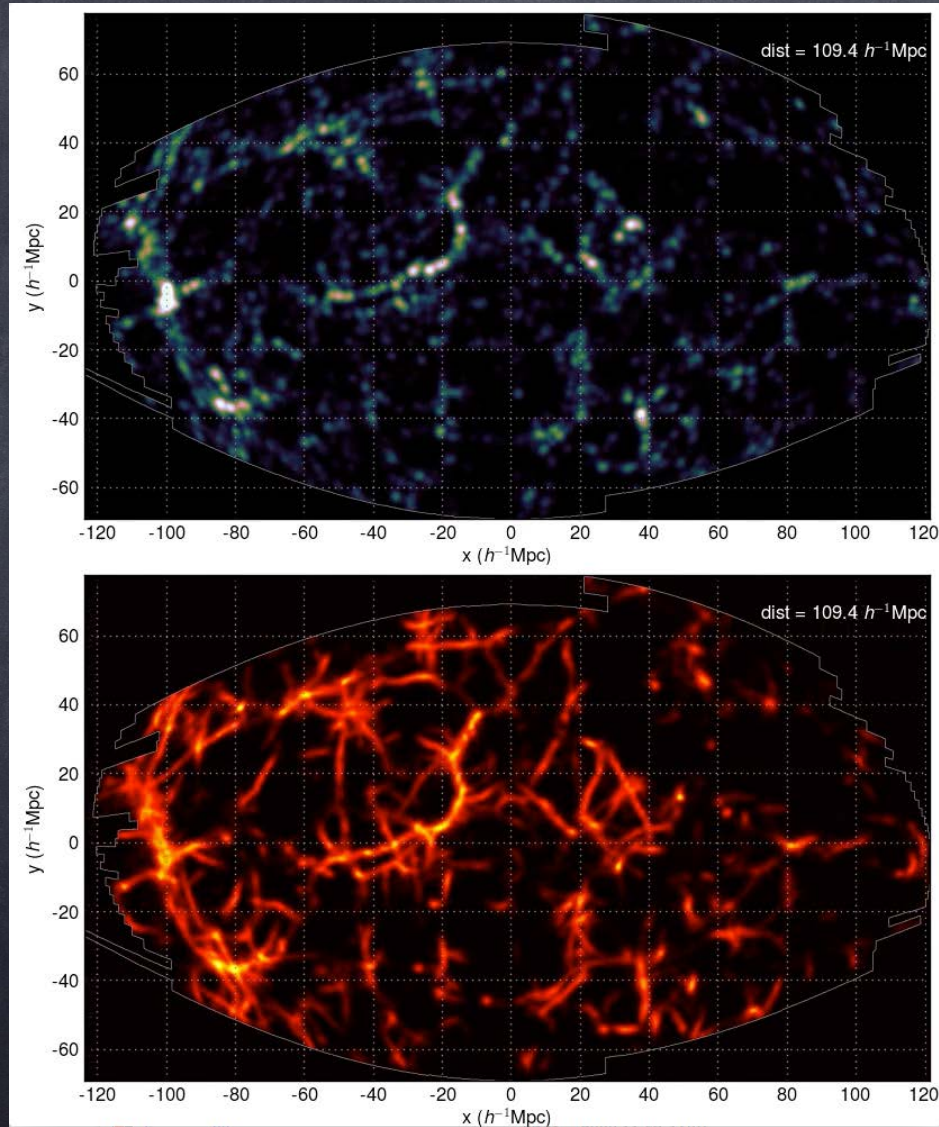
Juhan Liivamägi

Toni Tuominen

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

Tempel, Libeskind, Hoffmann et al. (2014)
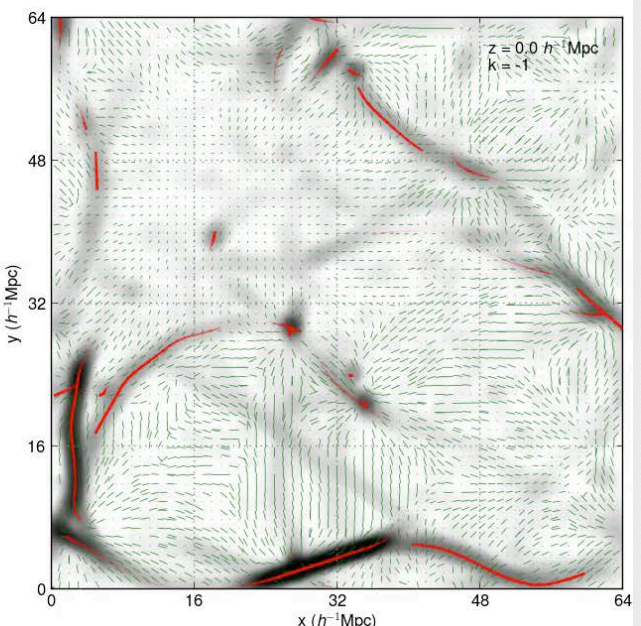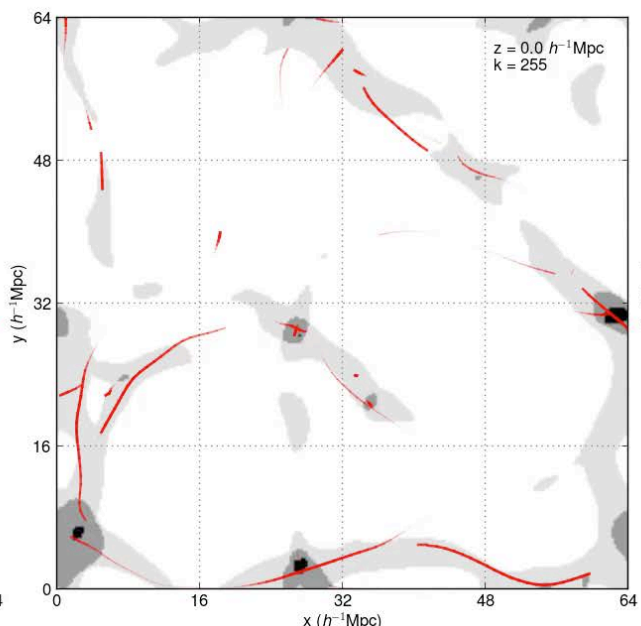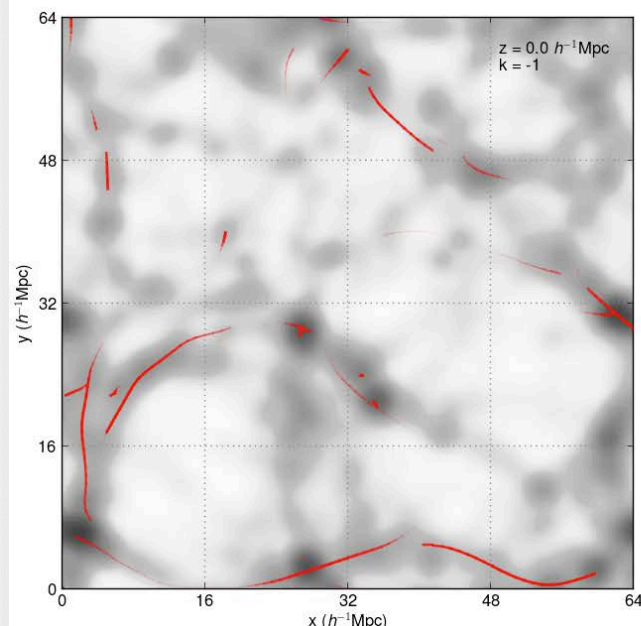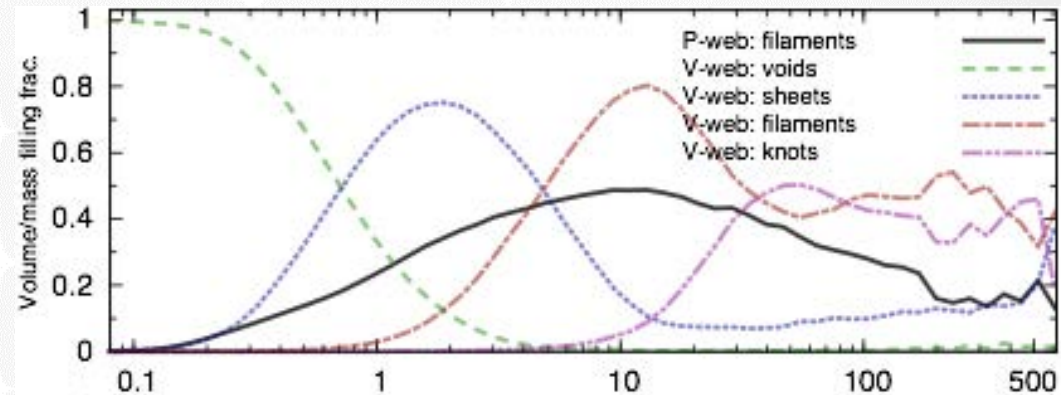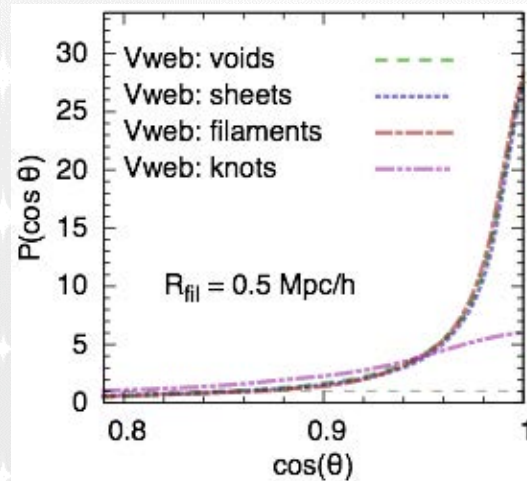
Filaments in Eagle simulation: Bisous vs Nexus

Nexus: Dark Matter
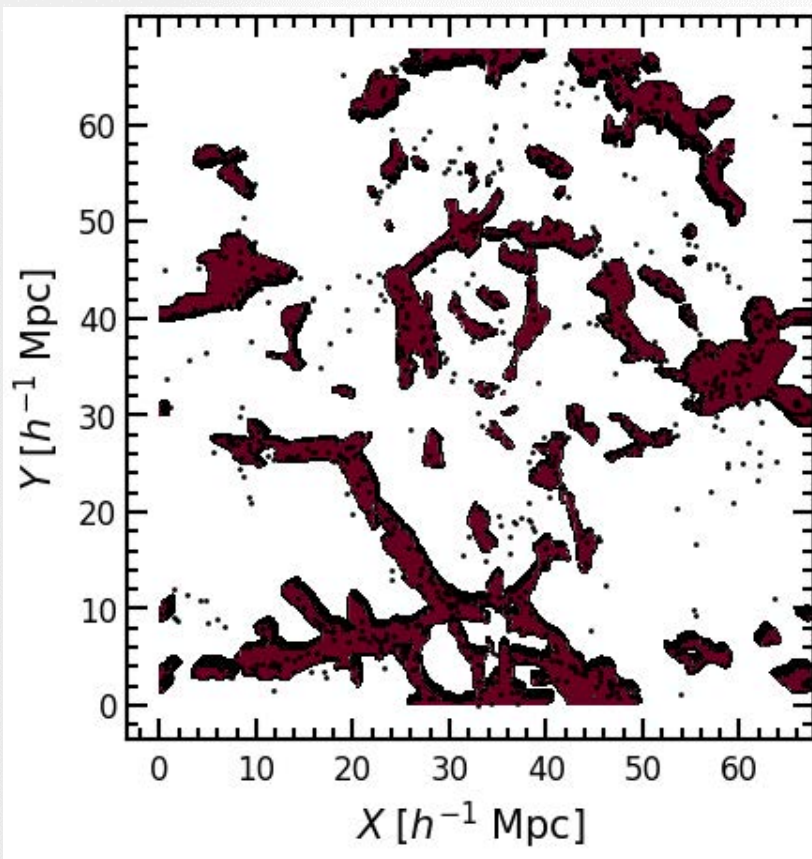
Bisous: galaxies
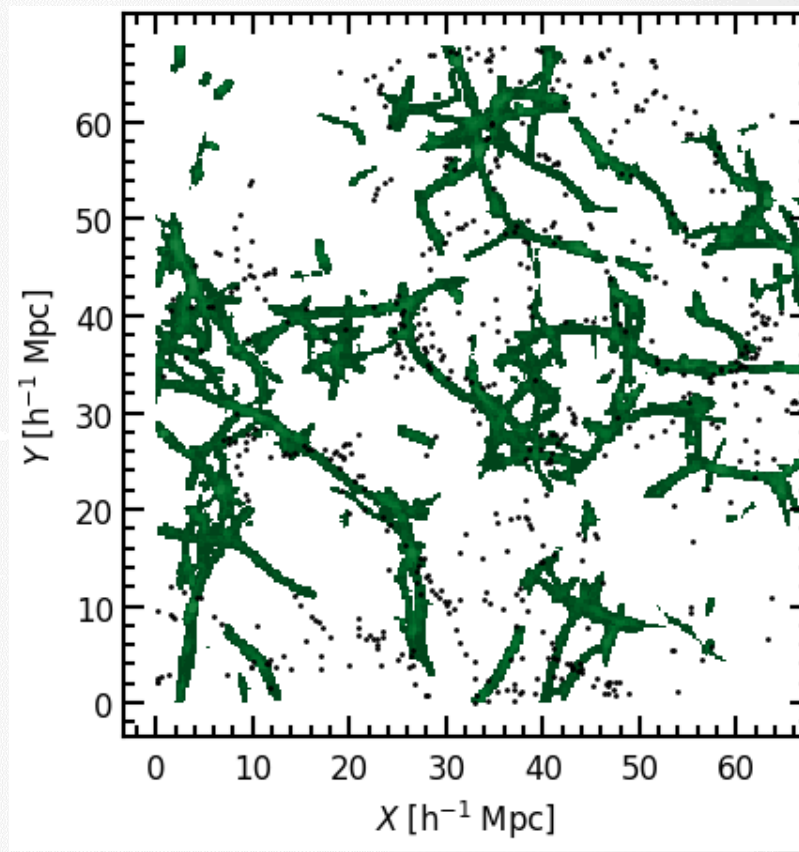
Bolshoi simulation

Density map   z = 1.11   Filament visit map

50 Mpc/h

ET, Stoica, Saar 2013
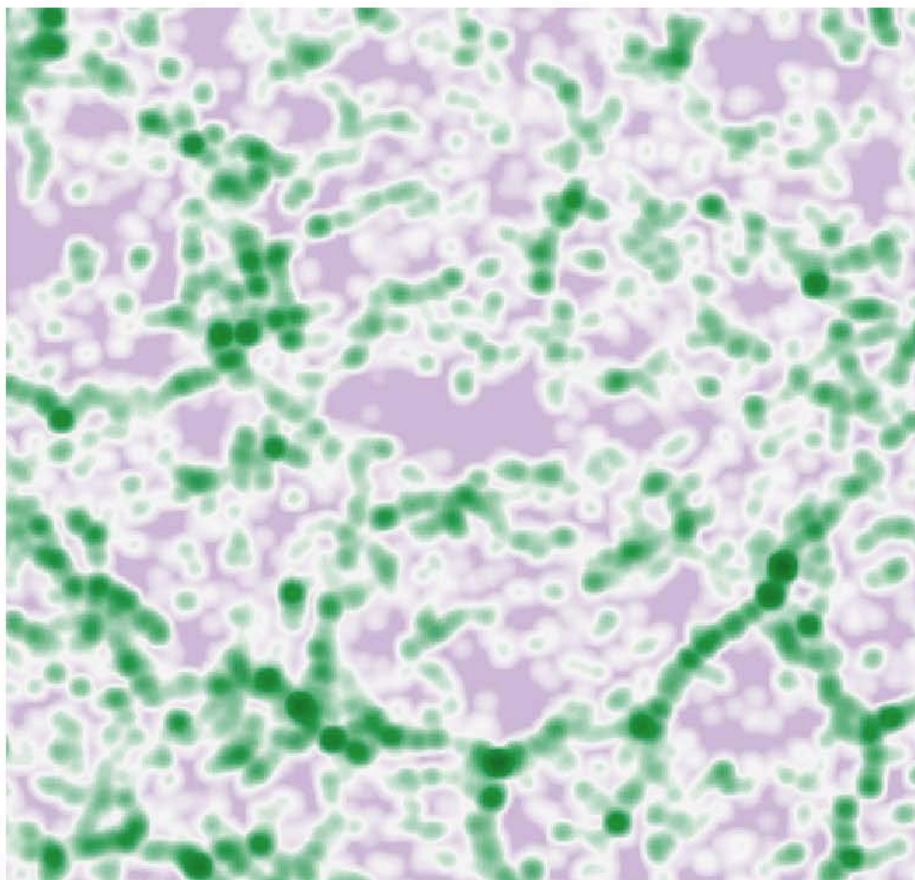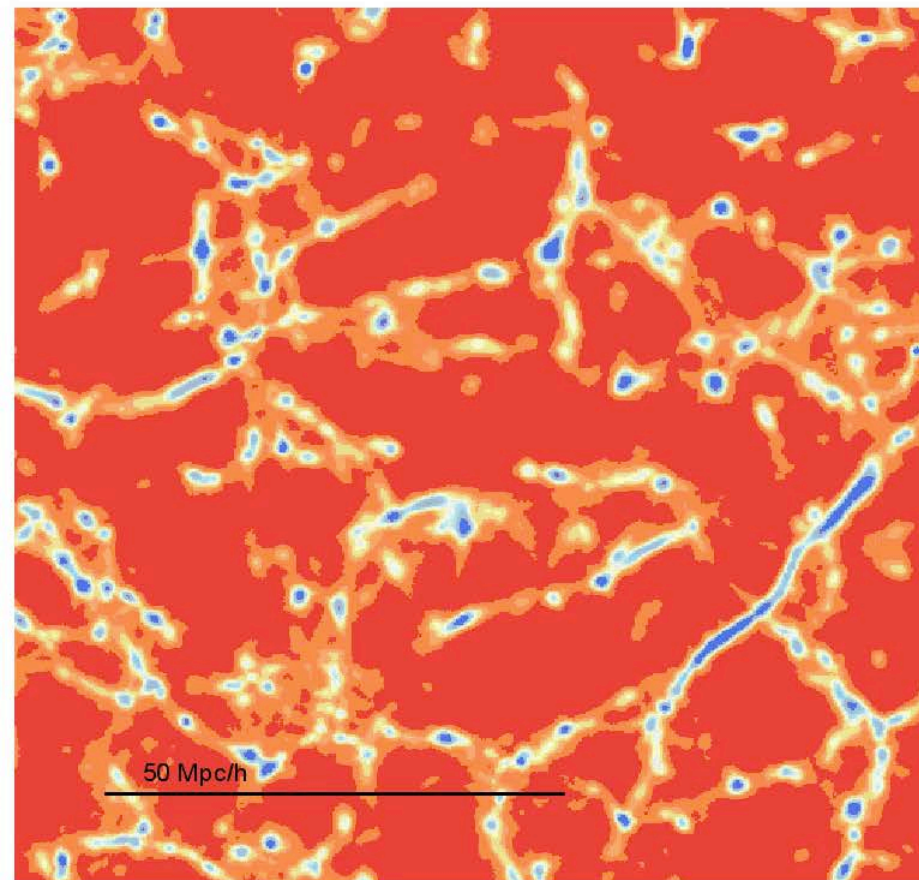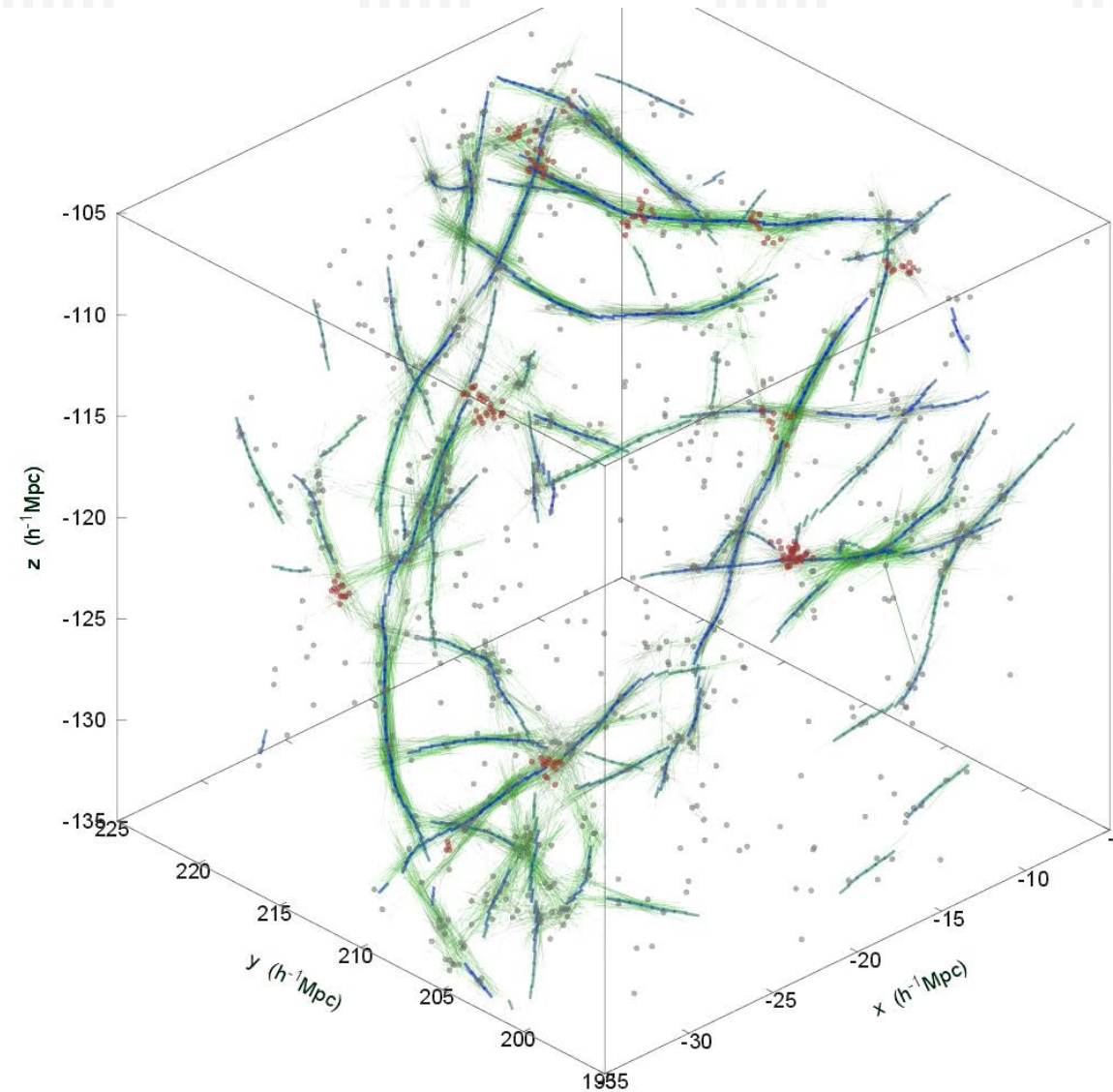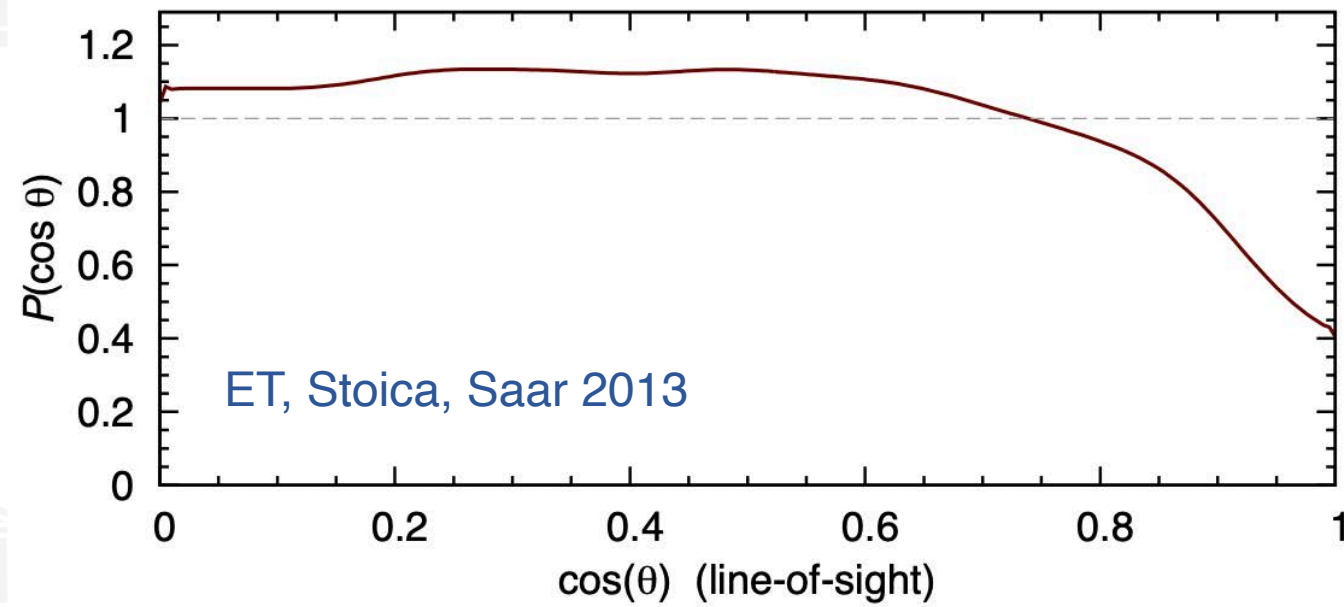
Redshift space distortions

Filament orientation is not uniform

Bisous model for filament detection:
ET et al. 2014, 2016

Galaxy filament alignment

Ellipticals

Spirals

e3-vector (parallel to filaments)

Elliptical galaxies

$<\cos(\phi)> = 0.479$ $<\sigma> = 3.38$

e3-vector (parallel to filaments)

Spiral galaxies

$<\cos(\phi)> = 0.513$ $<\sigma> = 1.62$
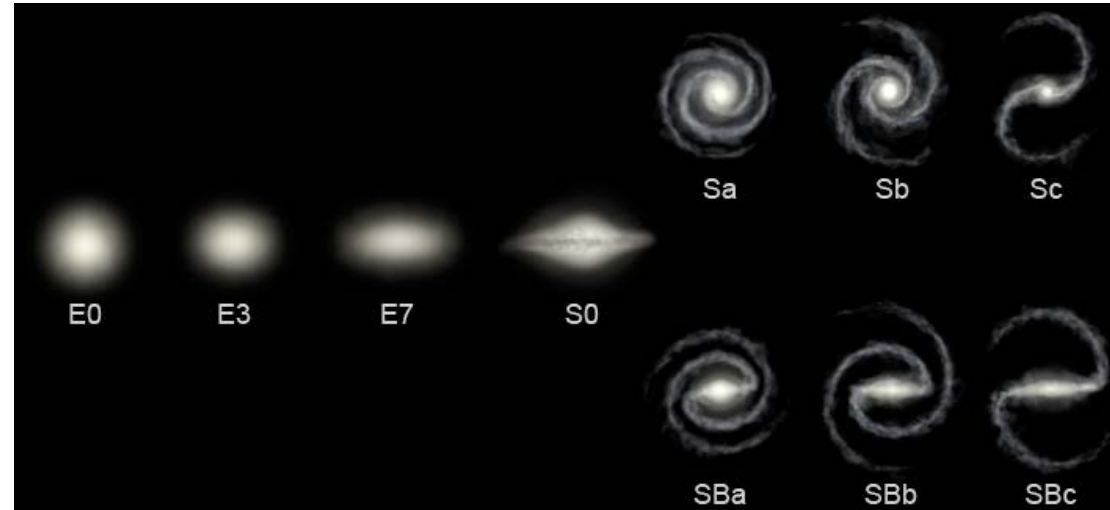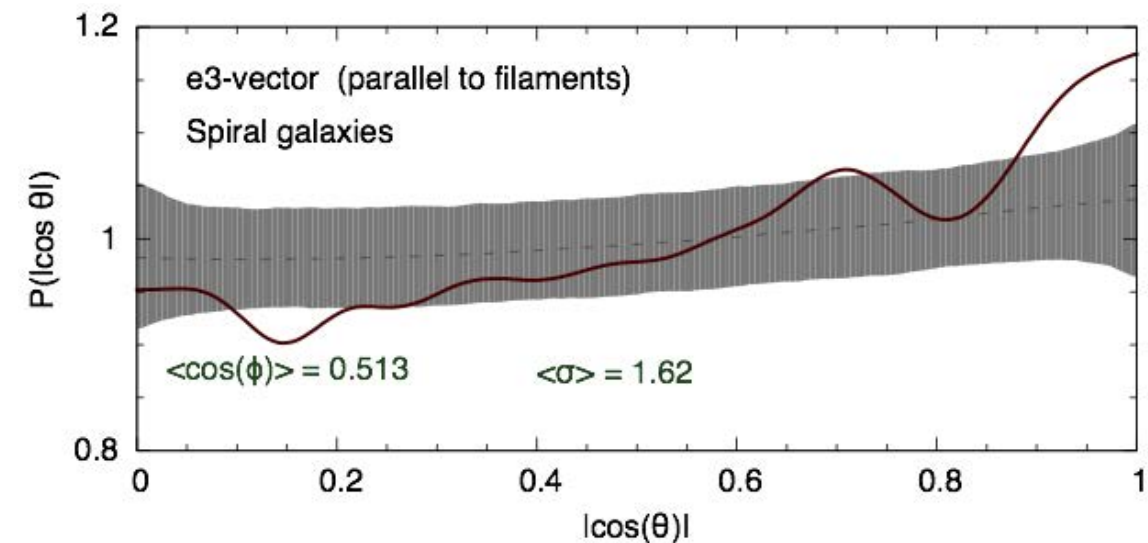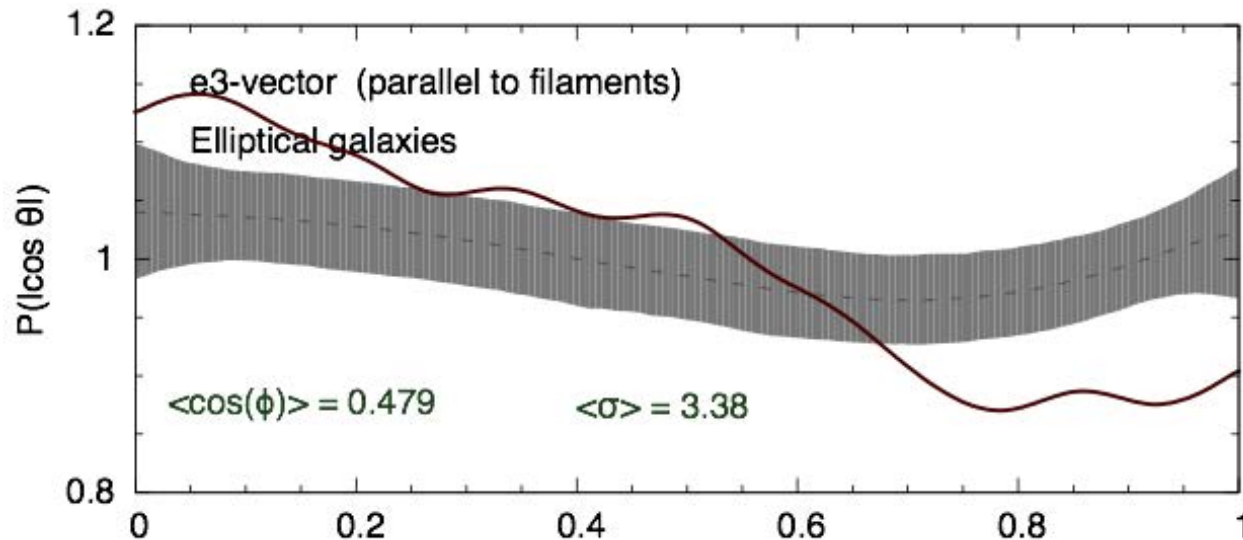
Tempel et al. (2013)

Filaments and galaxy formation

Inner part   Outer part

Tempel, Libeskind (2013)
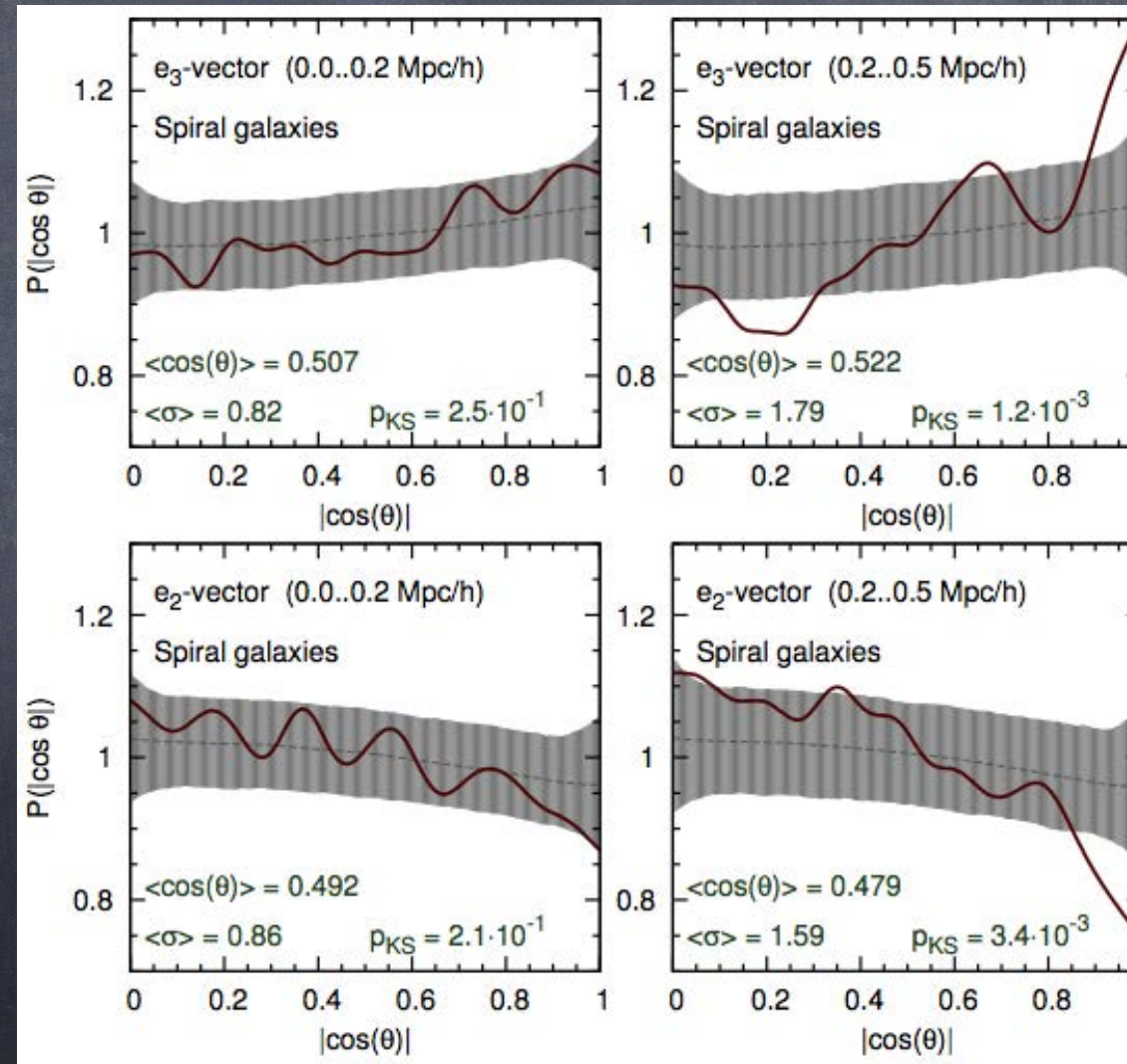
Galaxy filaments as pearl necklaces

Tempel et al. (2014)

Pair correlation function along the filaments

Examples of filaments and their spines

galaxy groups

excess at 7 Mpc/h

All filaments

Correlation length (Mpc/h)

186
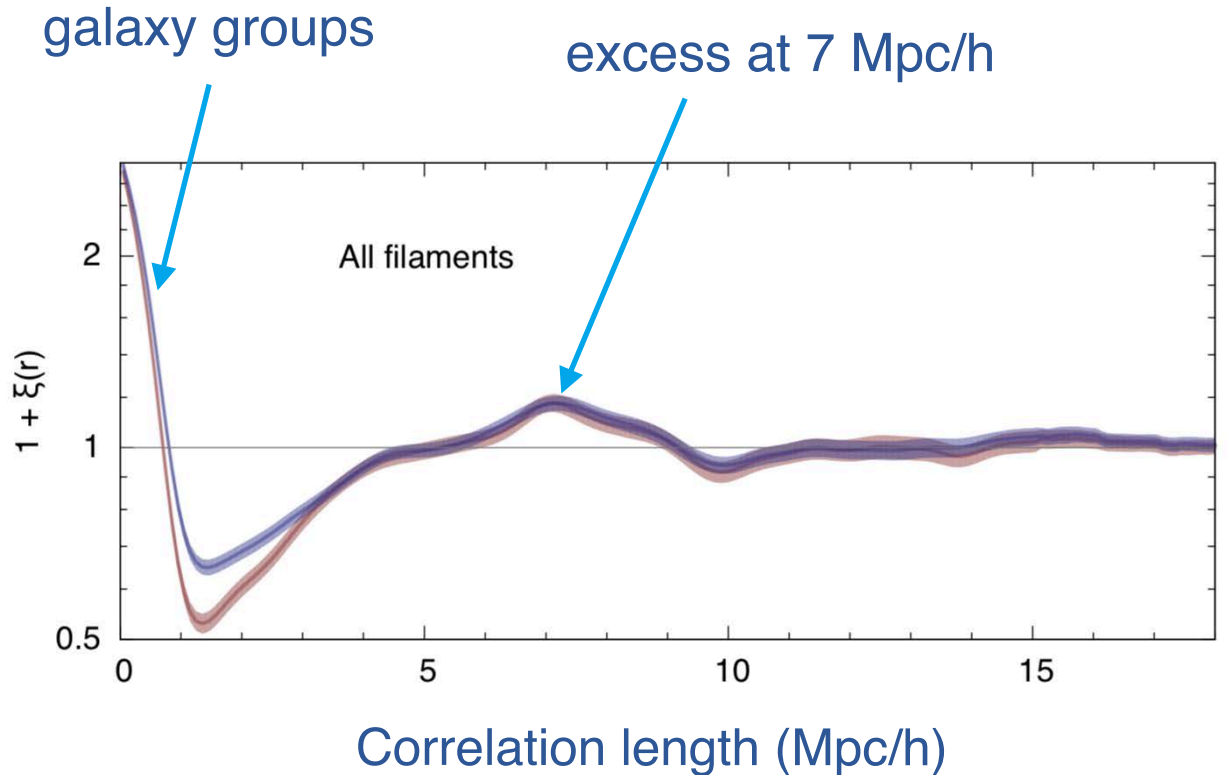
Data and methods
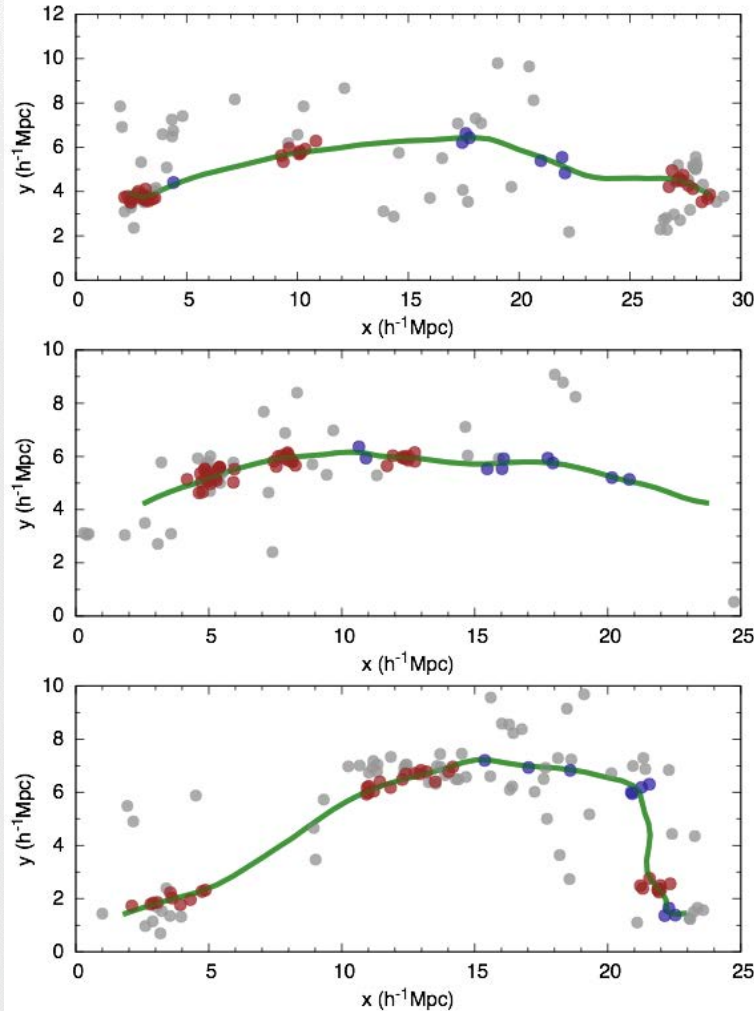
Pair correlation function:

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

Rayleigh Z-squared statistics:

The algorithm works as following. For each filament, we produce a periodogram using the Z_1^2 (Rayleigh statistics),

$$Z_1^2 = \frac{2}{N}\left[\left(\sum_{j=1}^{N}\cos\phi_j\right)^2 + \left(\sum_{j=1}^{N}\sin\phi_j\right)^2\right], \qquad (4)$$

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.

Galaxy pairs align with galactic filaments

Tempel & Tamm (2015)
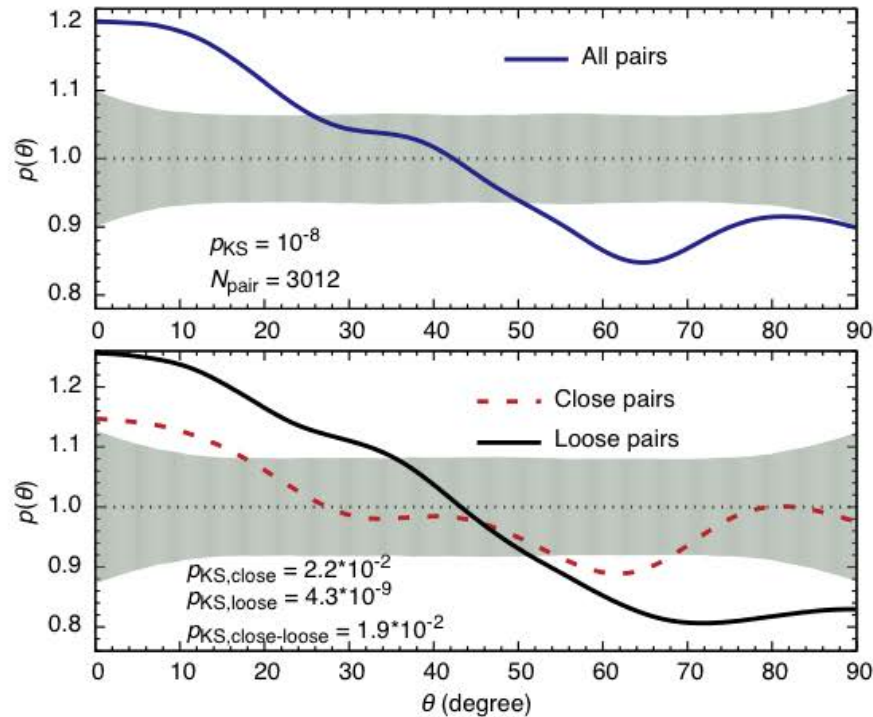
Fig. 2. *Upper panel*: probability distribution function (blue solid line) of the projected (in the plane of the sky) angles between galaxy pairs and their host filaments. The KS-test value that the sample is drawn from a uniform distribution is 10^{-8}. The filled area shows the 95% confidence region for a randomised distribution of 3012 pairs. *Lower panel*: the same as in the upper panel for two equal-size subsamples: close pairs ($d_{sep} < 0.3$ Mpc; red dashed line) and loose pairs ($d_{sep} > 0.3$ Mpc; black solid line).
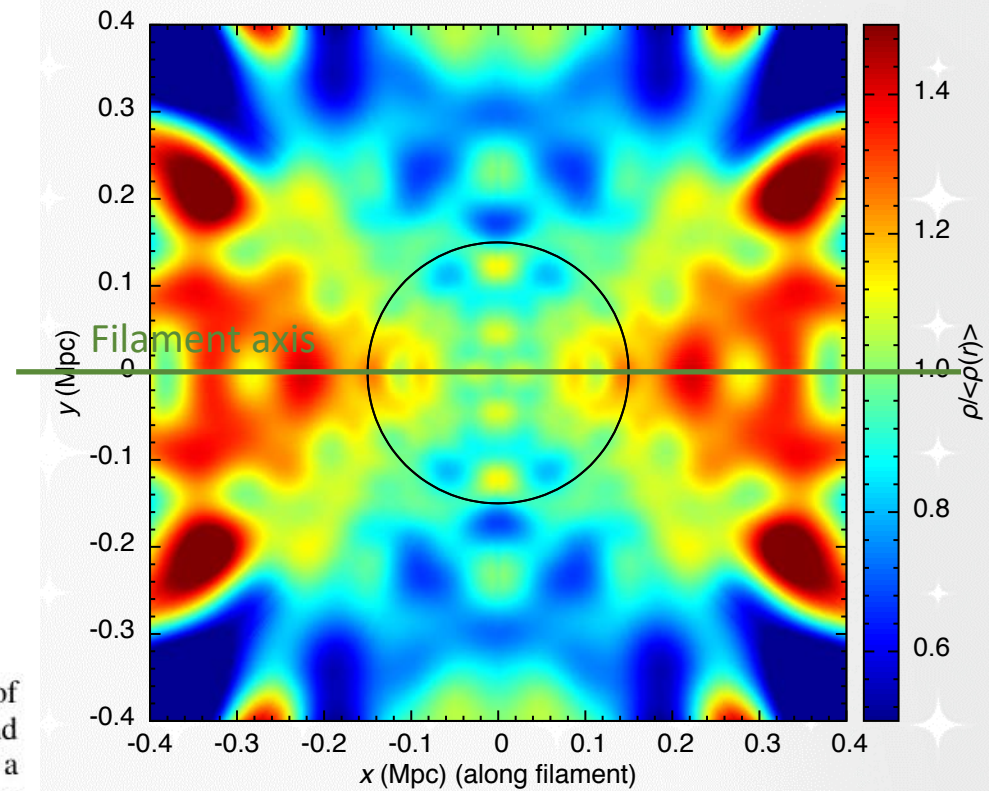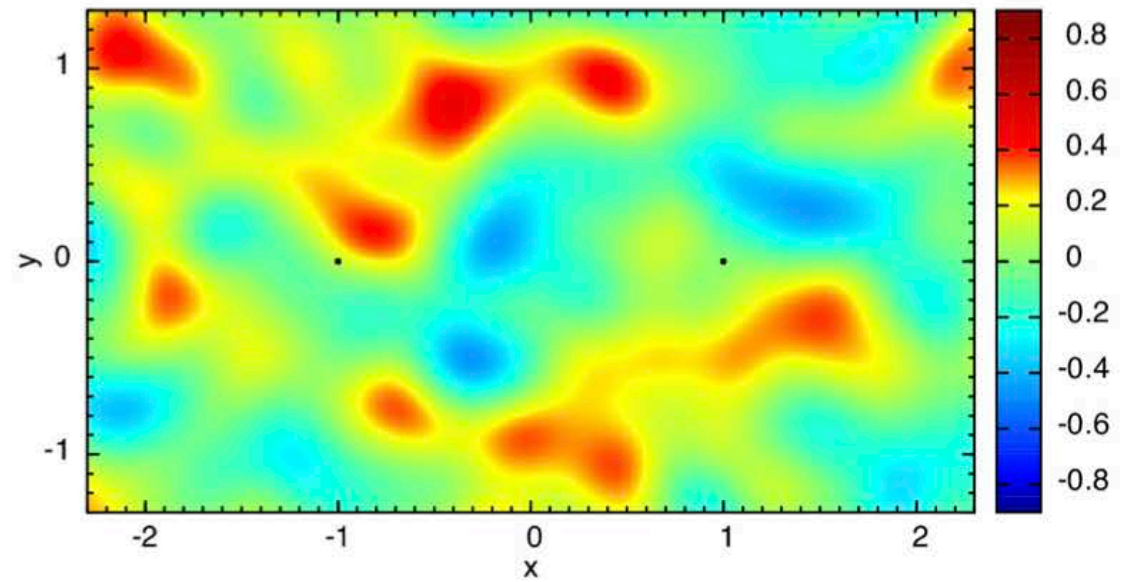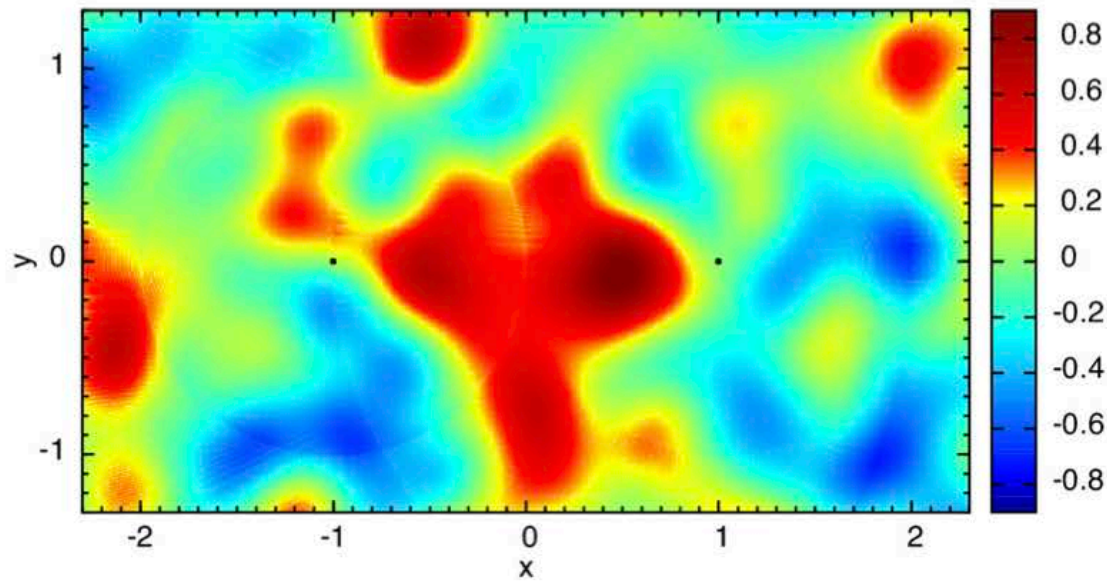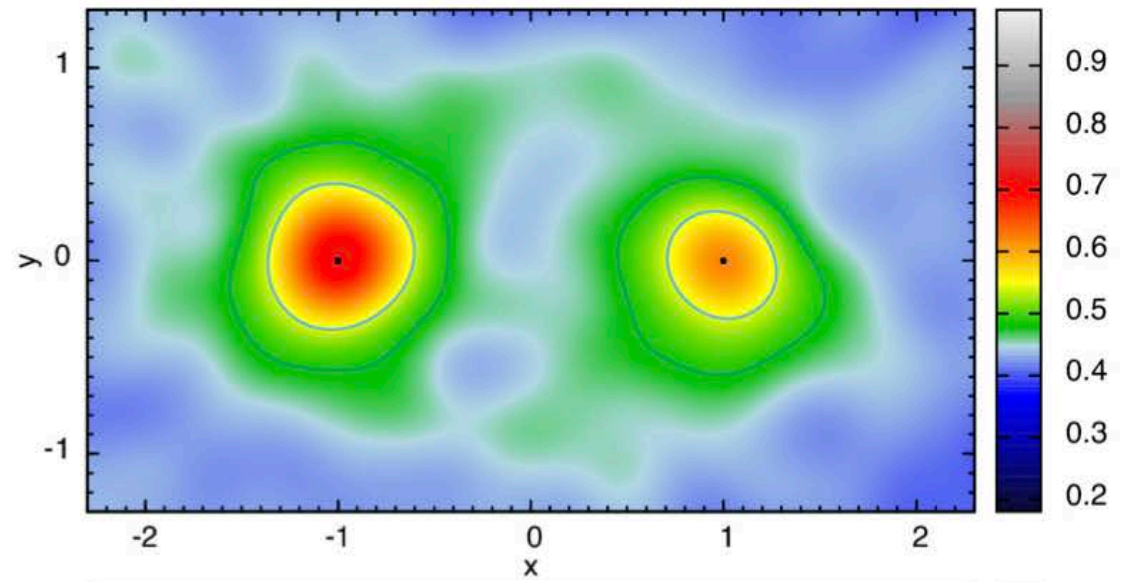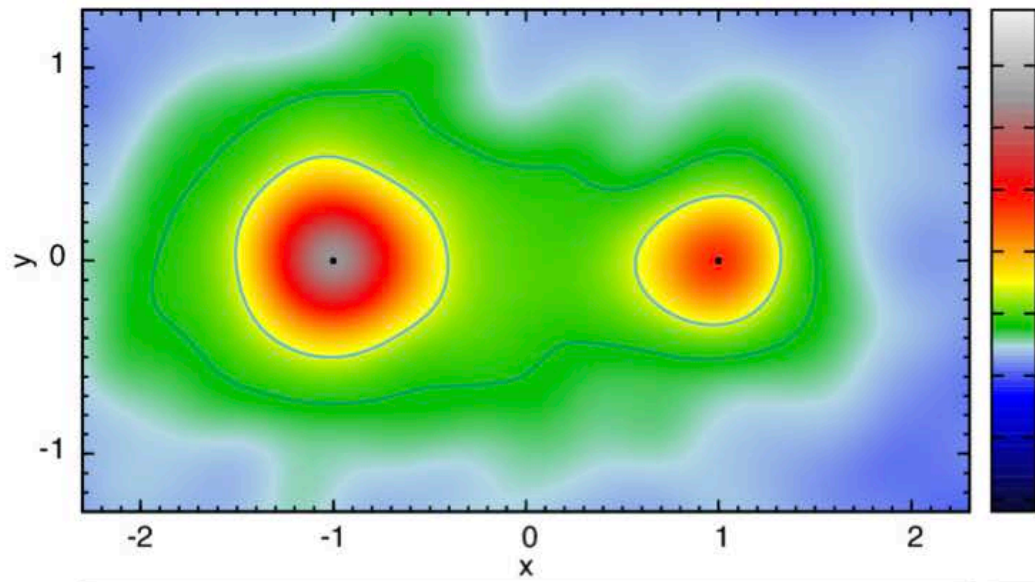
Satellite galaxies

Galaxy properties in filament environment

Kuutma, Tamm & Tempel (2017)
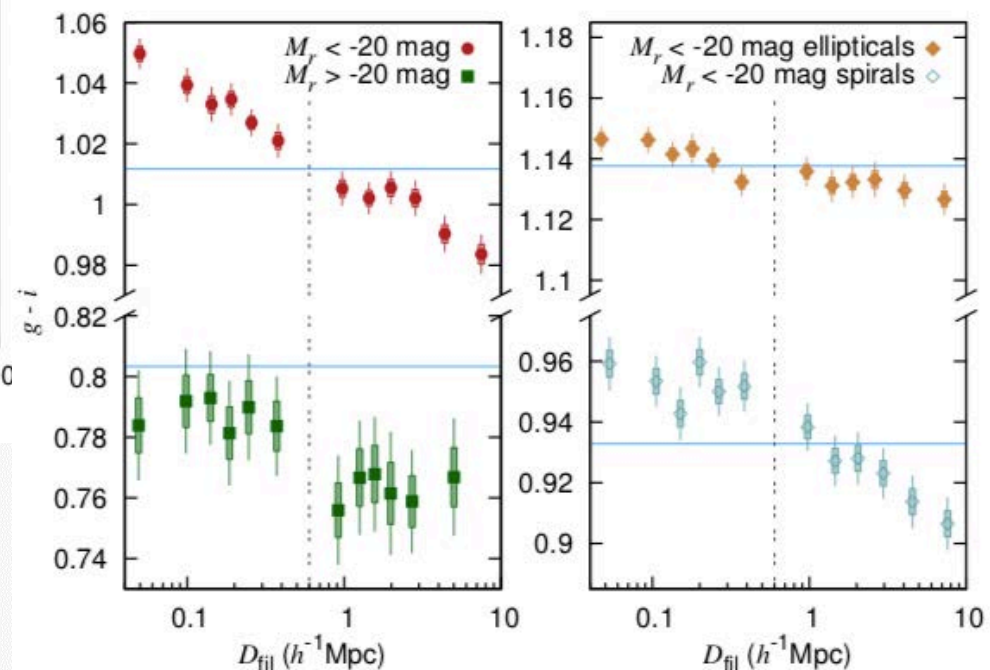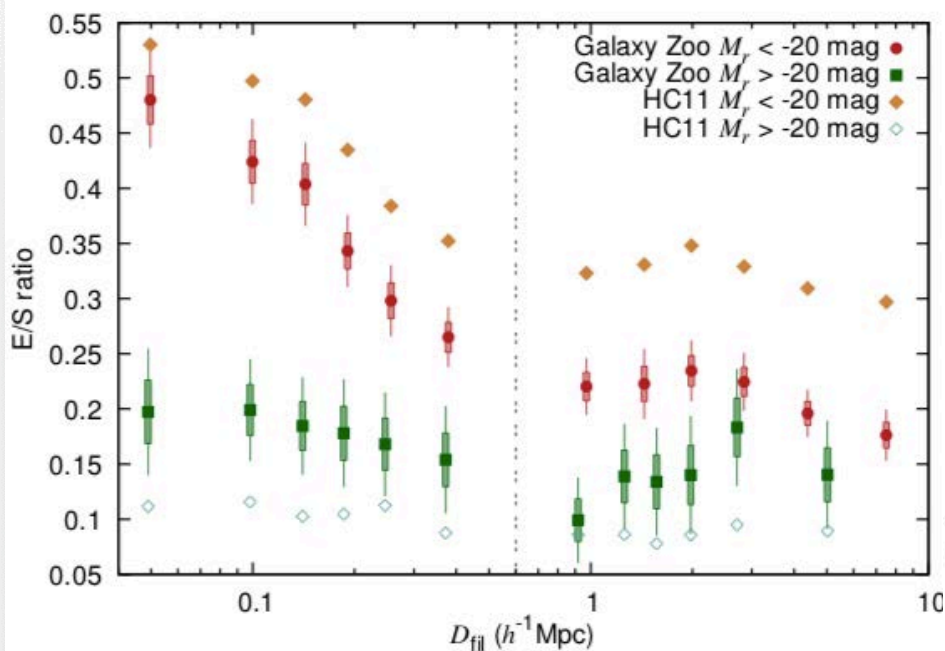
Galaxies in filaments have more satellites: the influence of the cosmic web on the satellite luminosity function in the SDSS

Guo, Tempel & Libeskind (2015)

Number of satellites
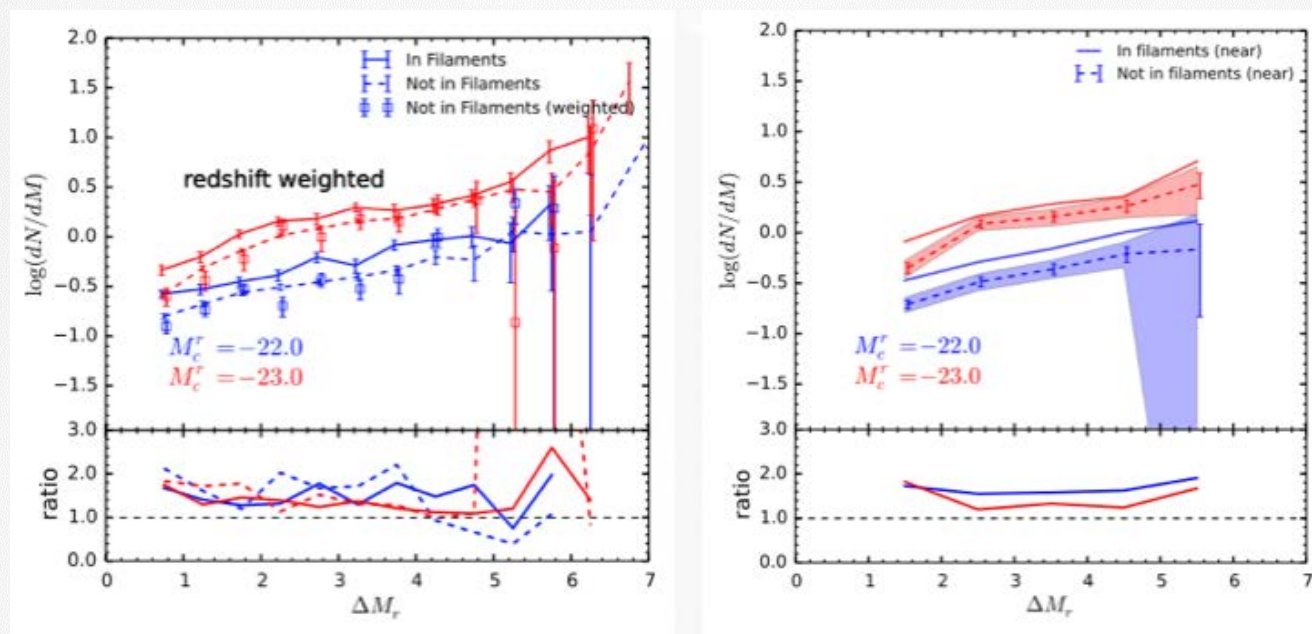
Satellite luminosity with respect to central galaxy

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

Tempel, Guo, Kipper, Libeskind (2015)
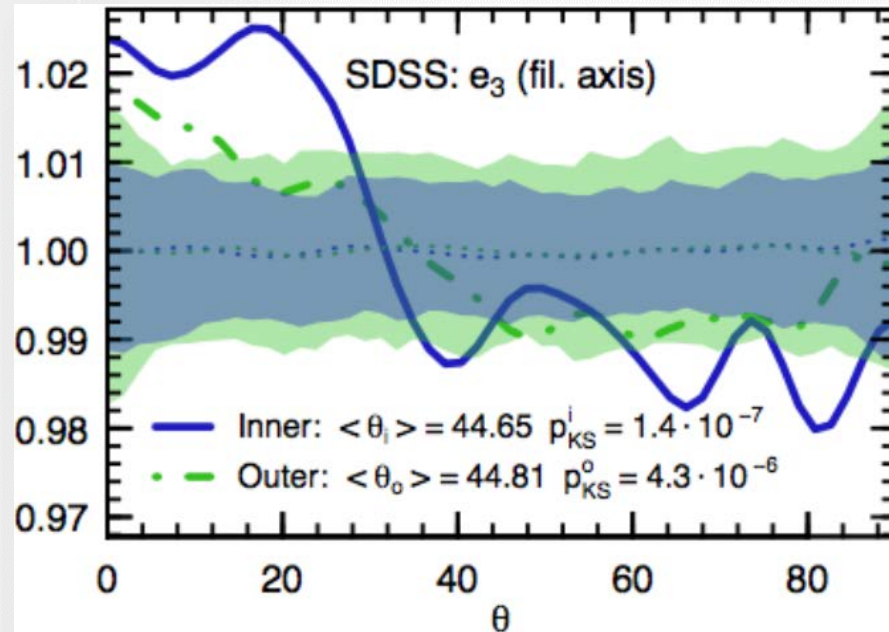
SDSS observations   Millennium simulation
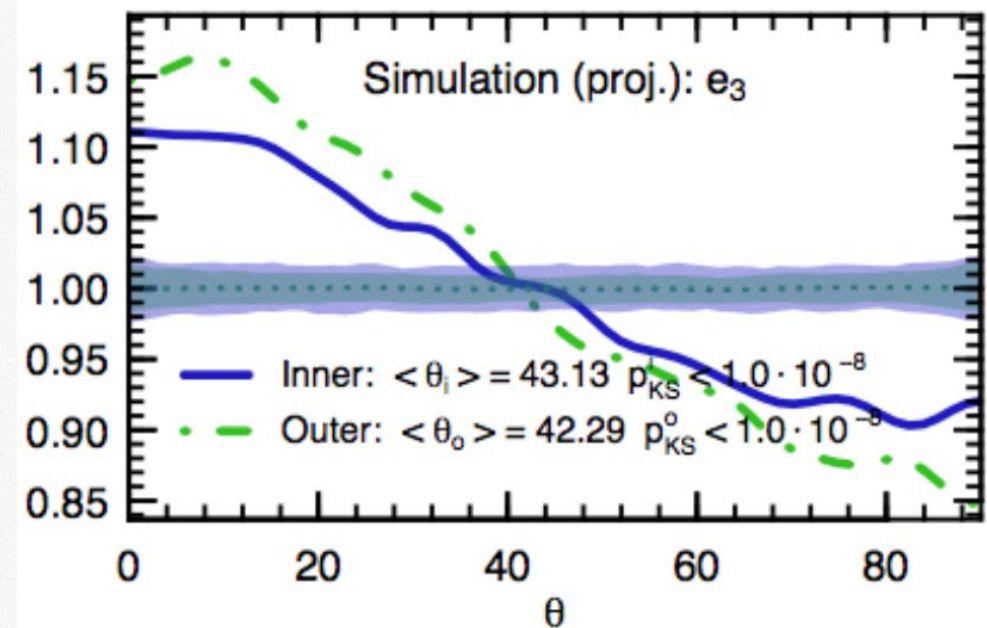
Angle between the satellite position and filament axis
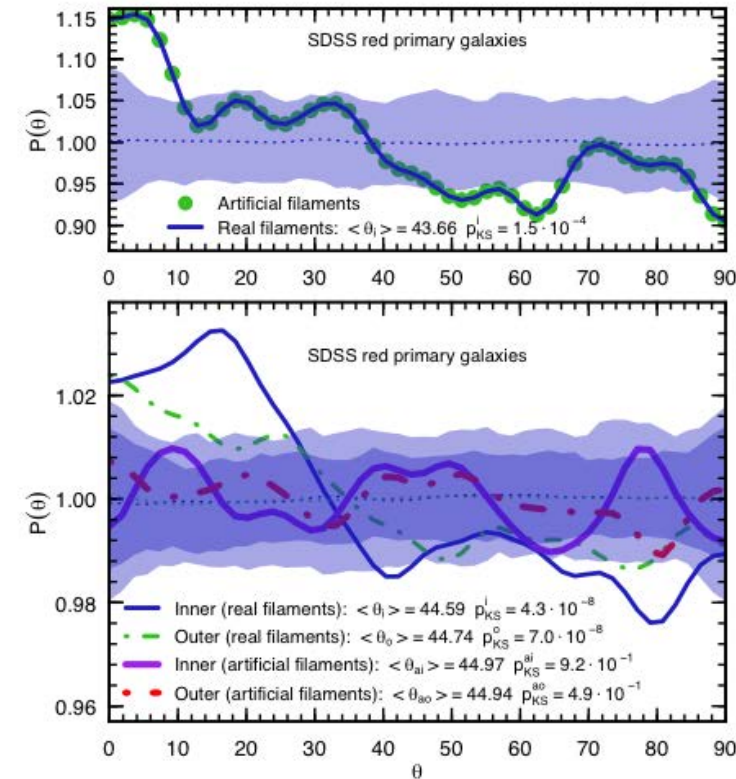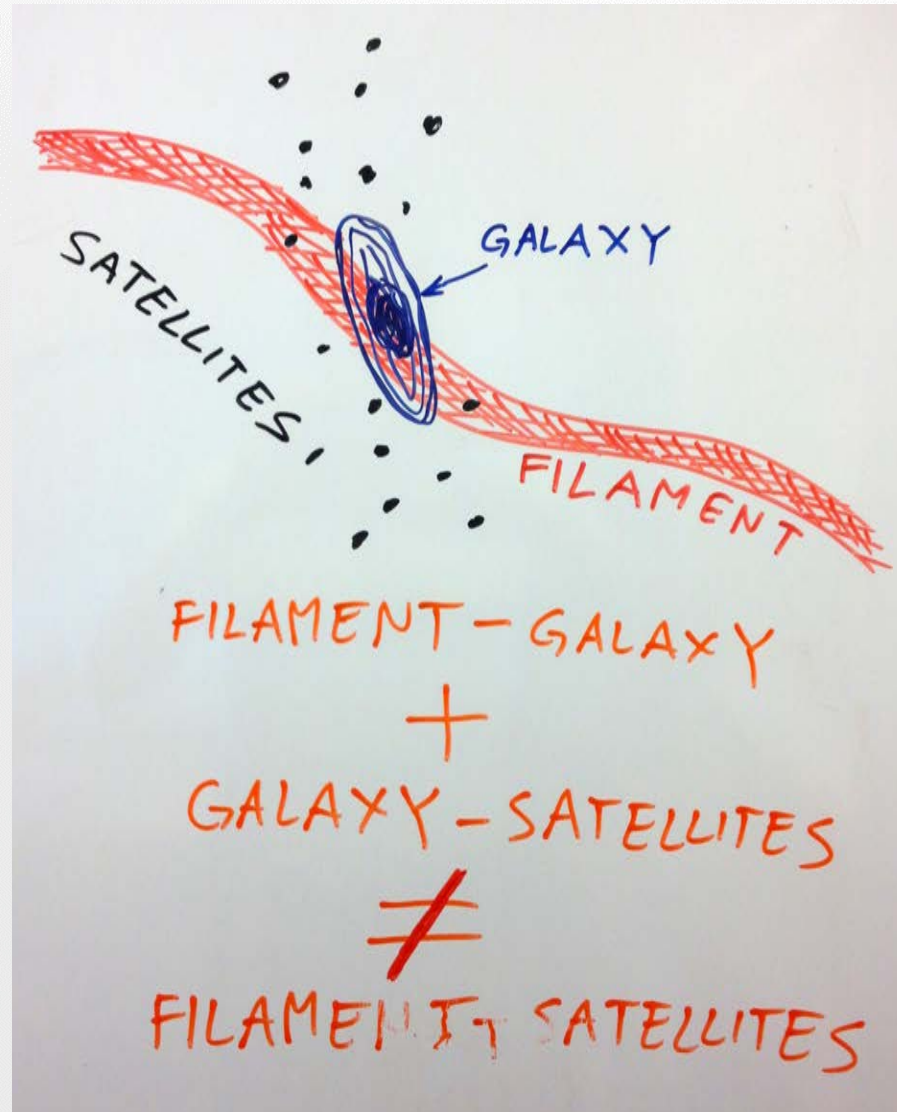
Figure 7. Test the intrinsic of the filaments between the filament axes and anisotropic distribution of satellites. *Top panel:* the alignment between real/artificial filament axes and the major axis of red primaries. *Bottom panel:* the alignments between anisotropic distribution of satellites with artificial filament axes (thick red and purple lines) and with real filament axes (thin blue and green lines).

Alignment dependence on filament properties

Ganeshaiah Veena et al.
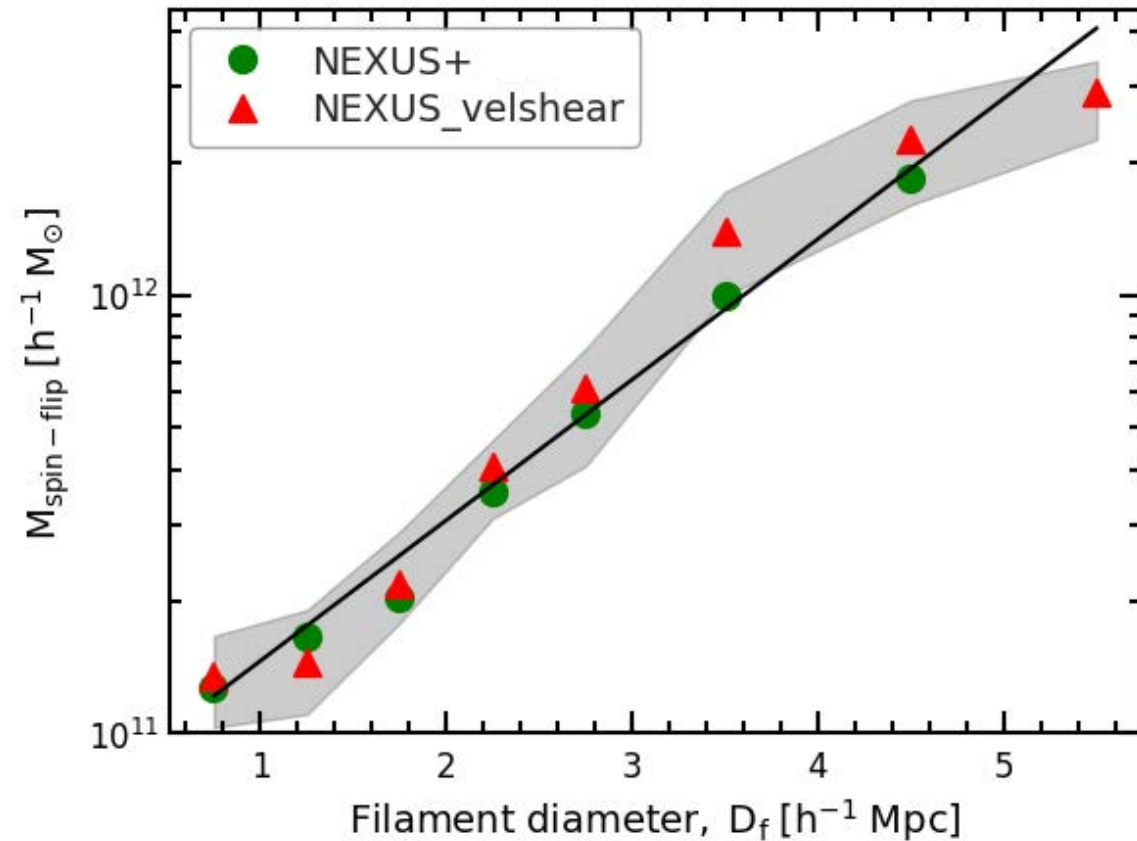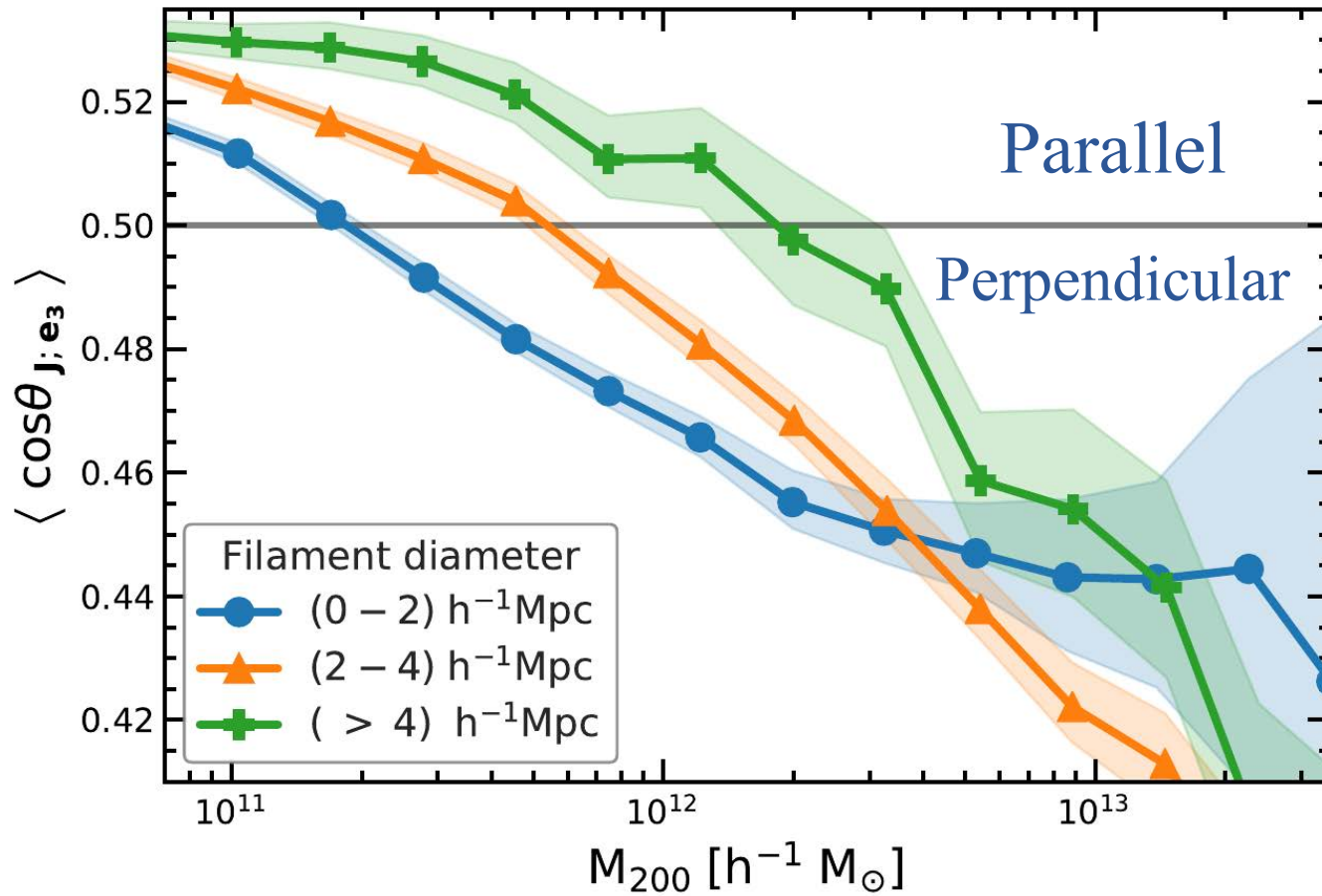
Late time accretion

ACCRETING HALO

Halo

STALLED HALO

50
10
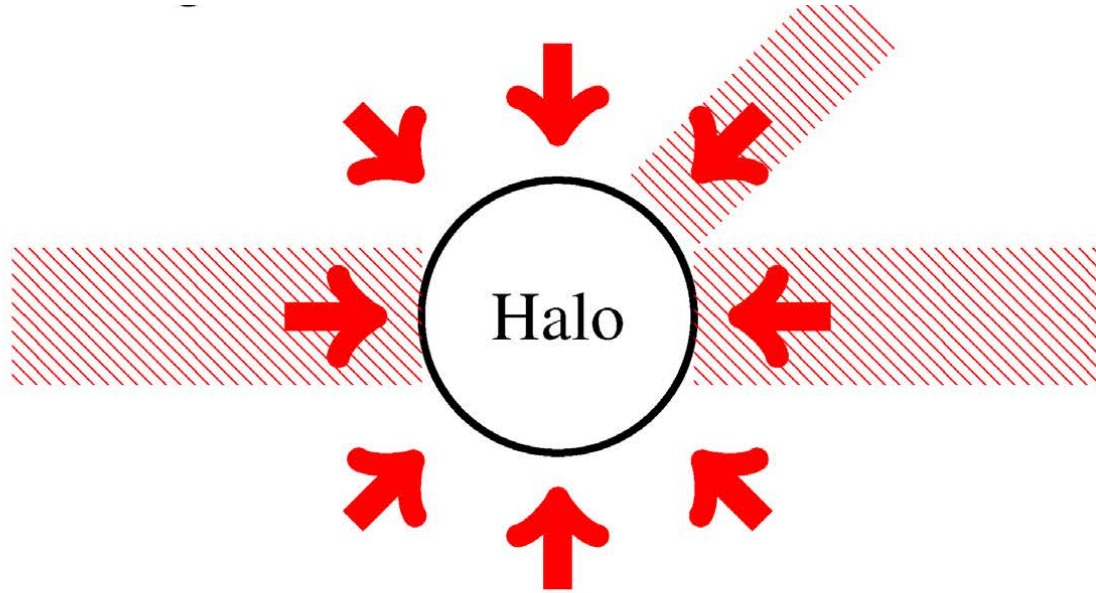
- Thin filament
- Accretion - perpendicular spin
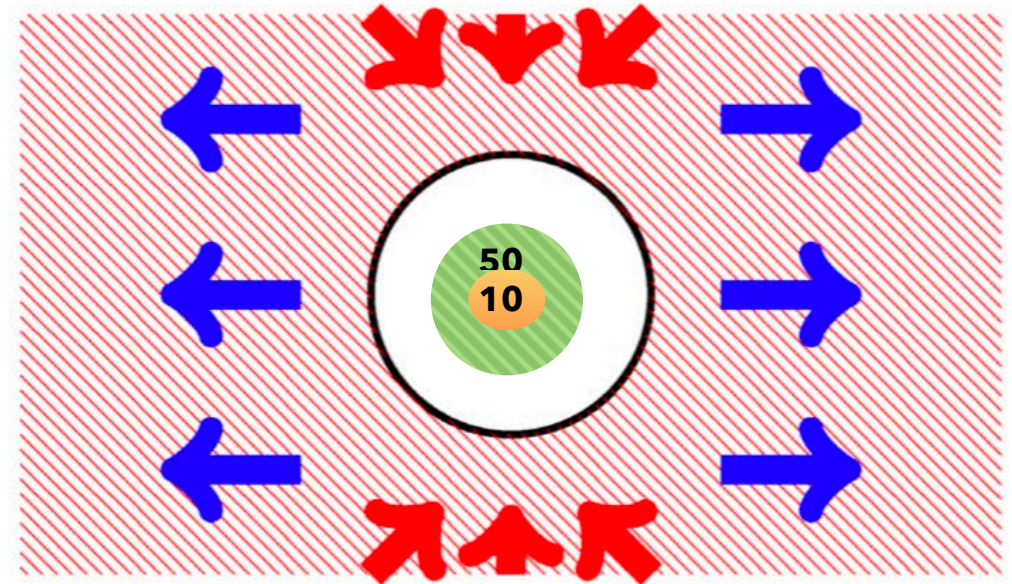
- Thick filament
- Accretion - parallel spin

Borzyszkowski et al. 2017, Ganeshaiah Veena et al. 2018

Rotating filaments

GAIN4MOST: Galaxy-filament Alignments IN 4MOST
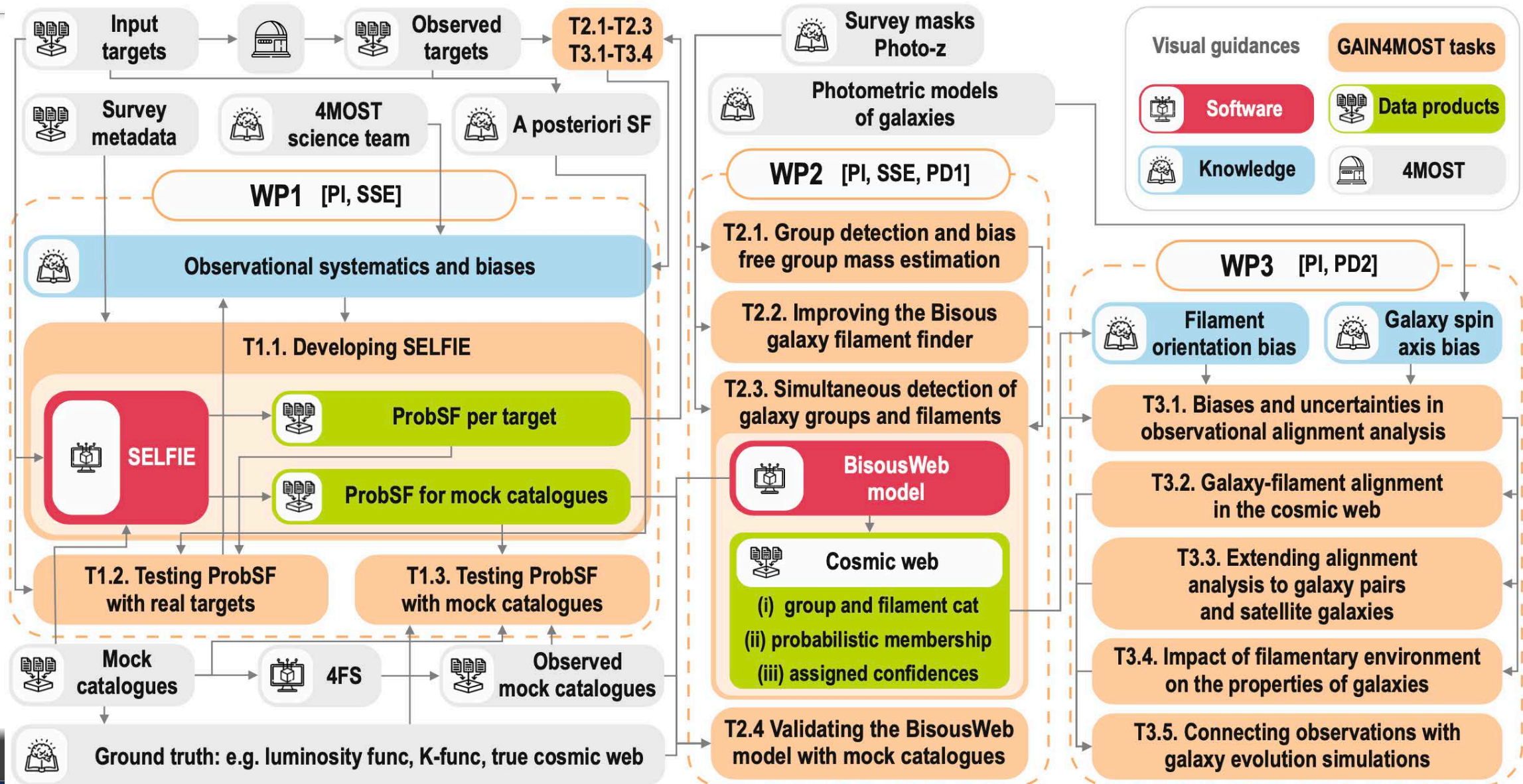
Elliptical galaxies

Spiral galaxies

e3-vector (parallel to filaments)
Elliptical galaxies

$<\cos(\phi)> = 0.479$ $<\sigma> = 3.38$

e3-vector (parallel to filaments)
Spiral galaxies

$<\cos(\phi)> = 0.513$ $<\sigma> = 1.62$

$|\cos(\theta)|$
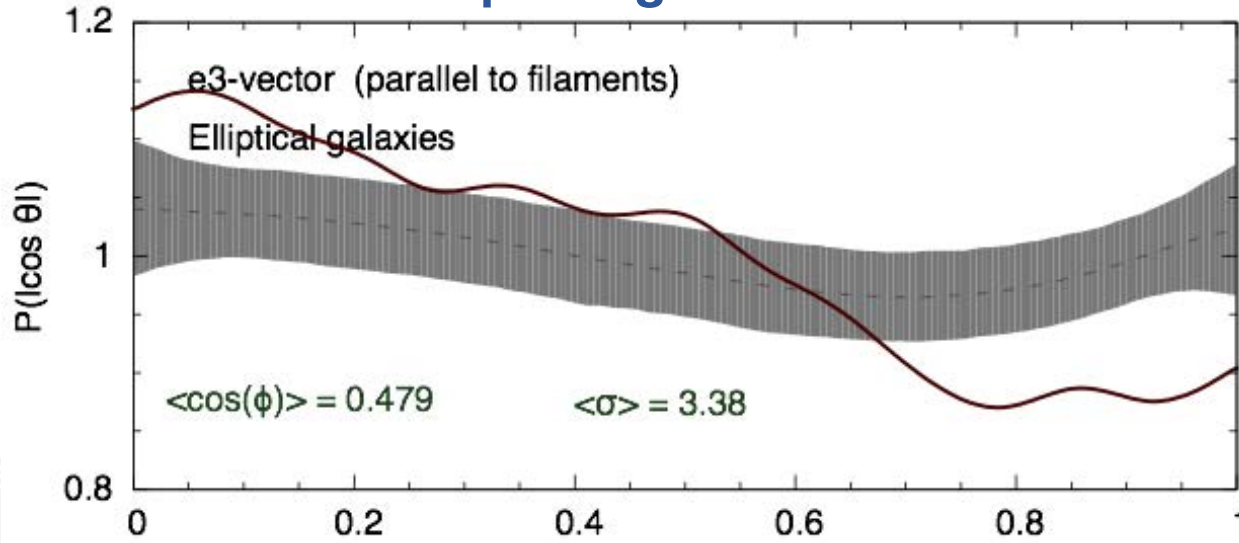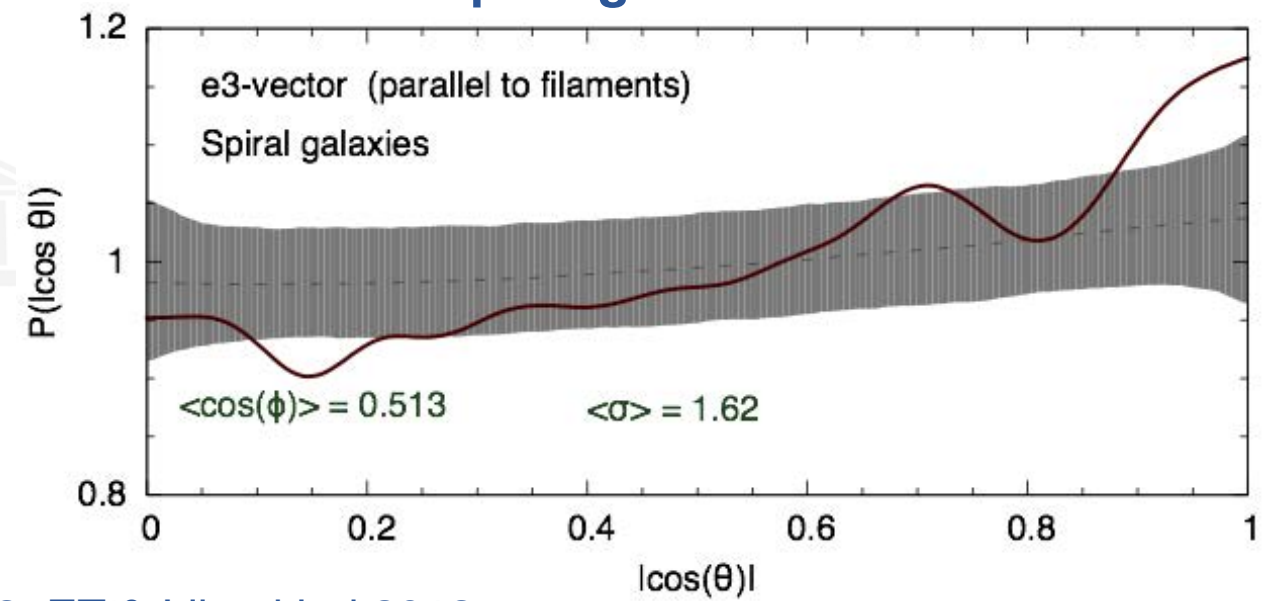
ET, Stoica & Saar 2013; ET & Libeskind 2013

Cosmic Web and Galaxy Evolution
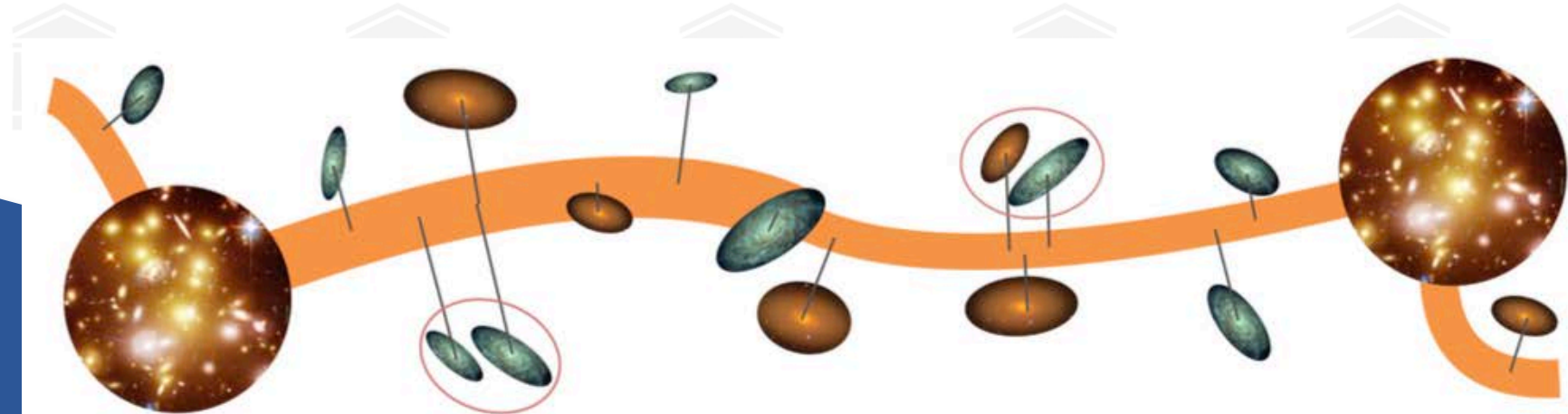
Fig. 4. A schematic illustration of galaxy-filament and galaxy-galaxy alignment in a filament that connects two clusters.
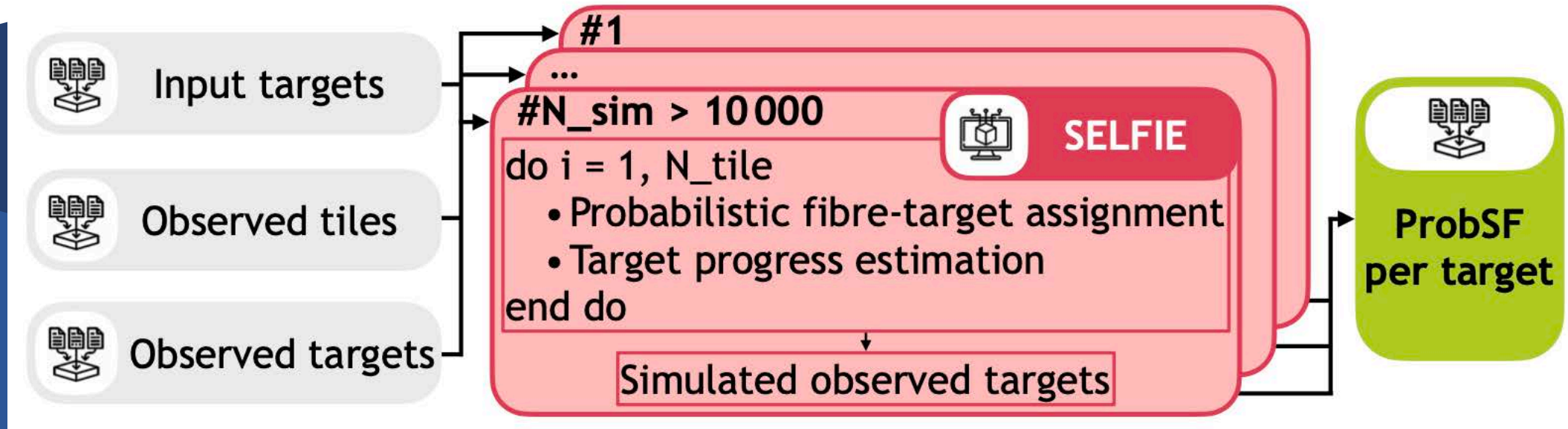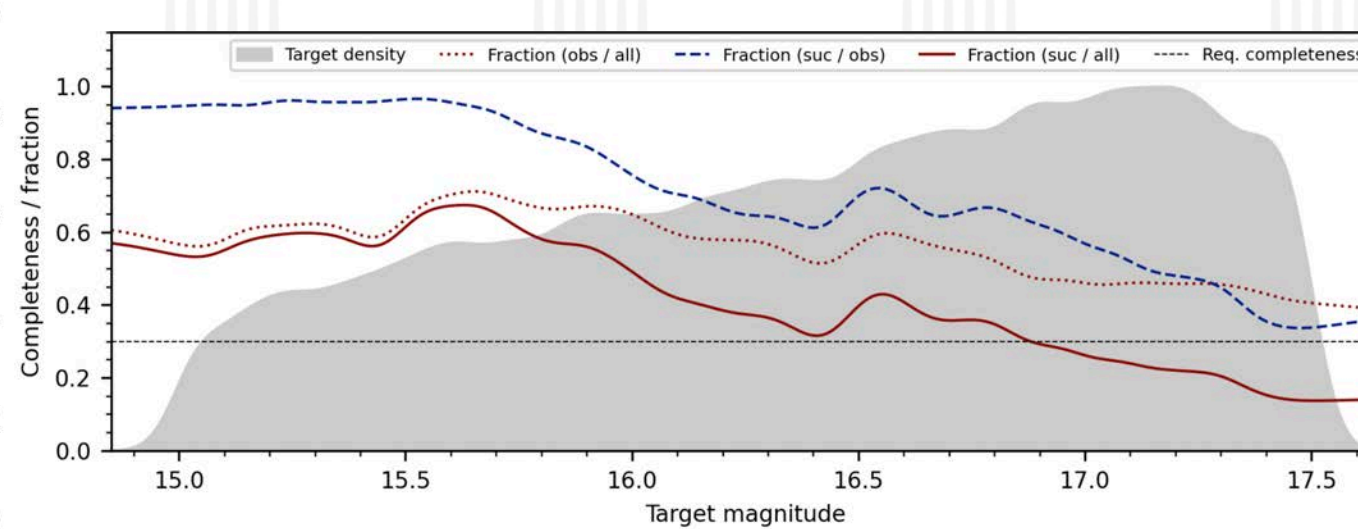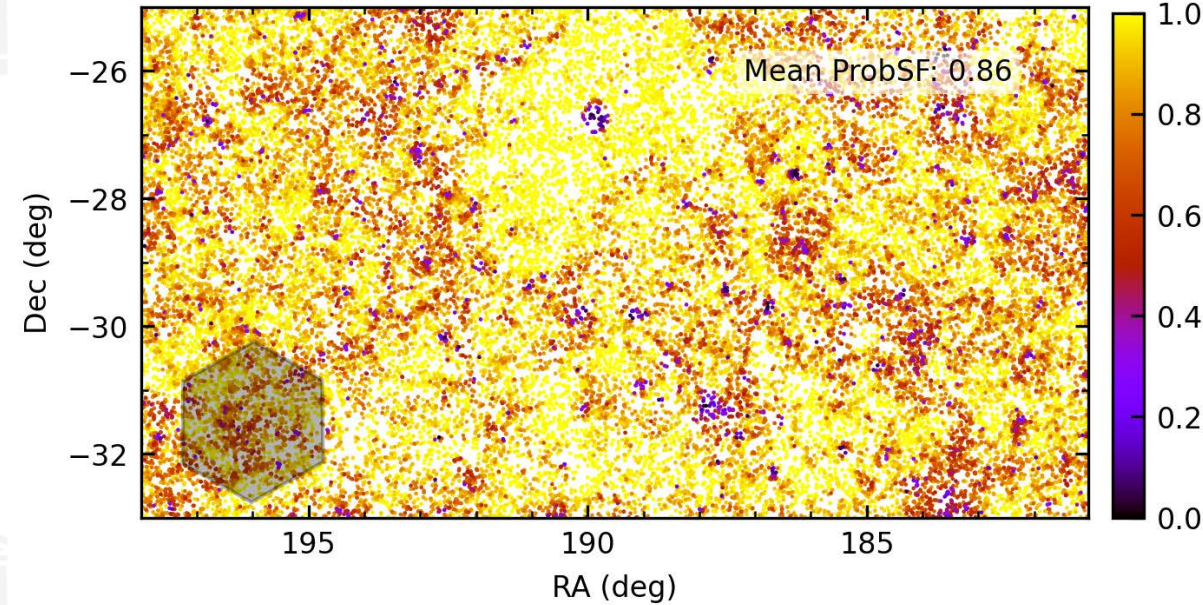
Probabilistic selection function

4MOST survey simulations

J-PAS – Javalambre Physics

of the Accelerating Universe Astrophysical Survey

J-PAS – Javalambre Physics
of the Accelerating Universe Astrophysical Survey
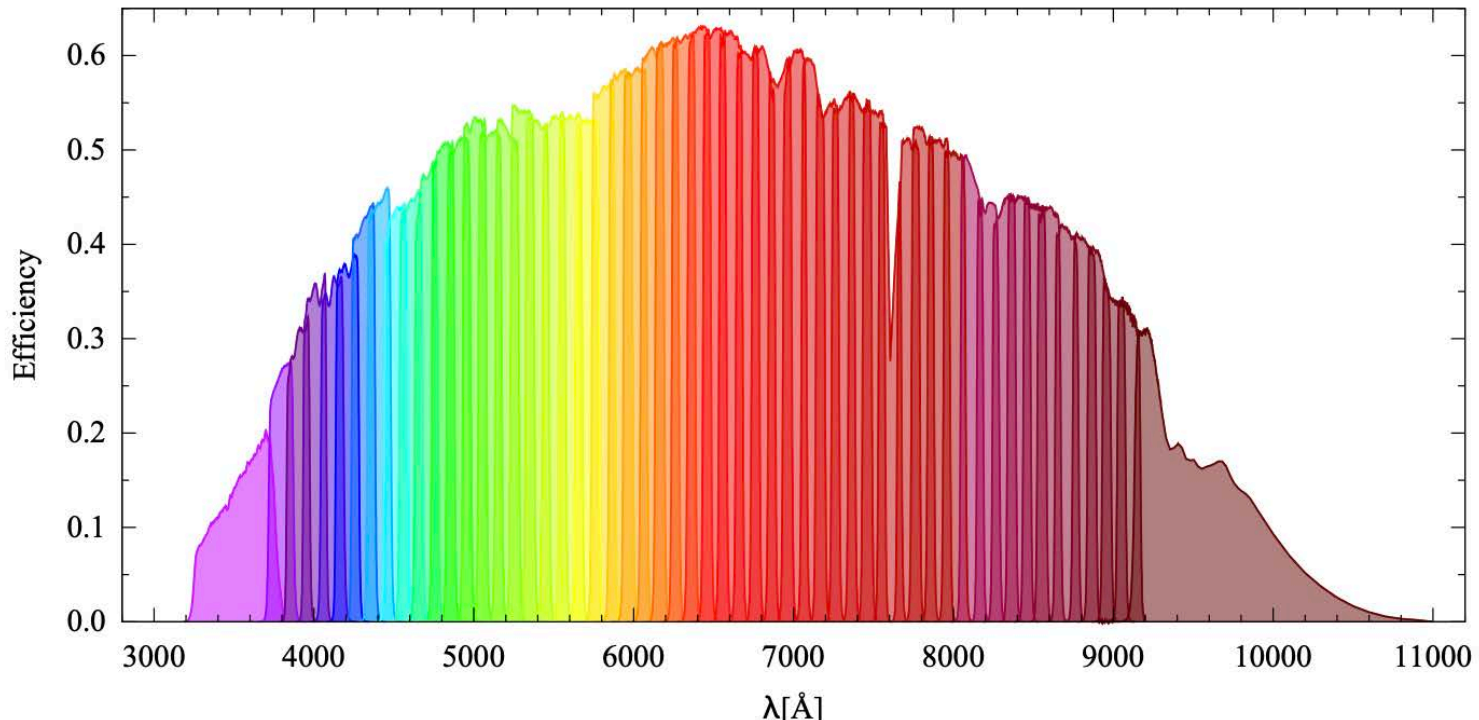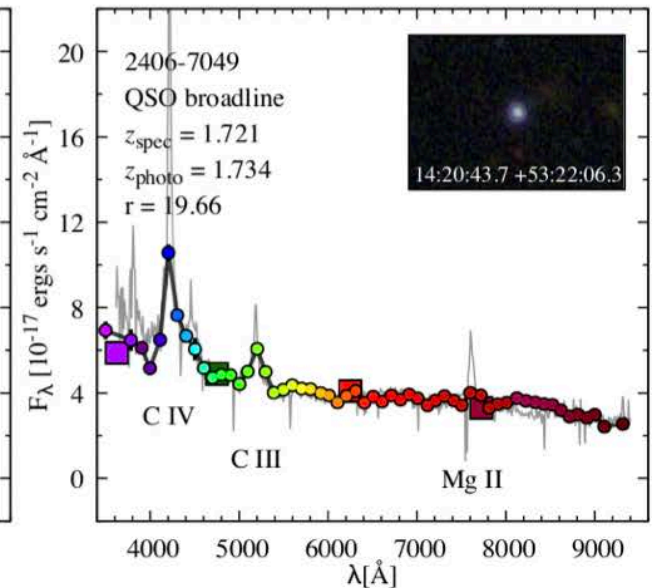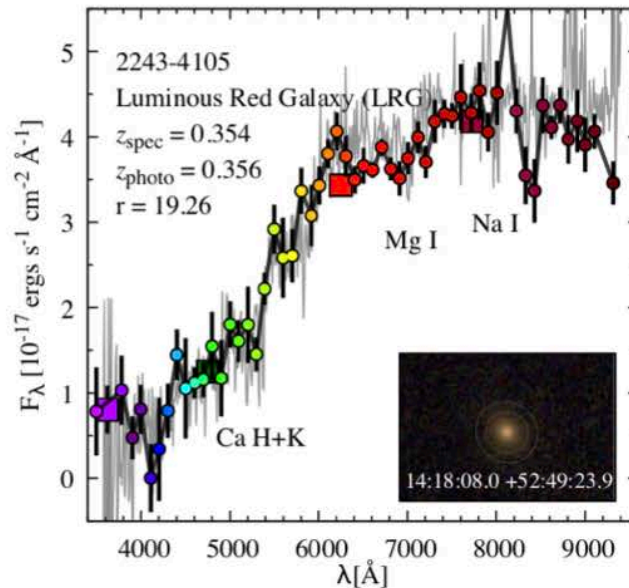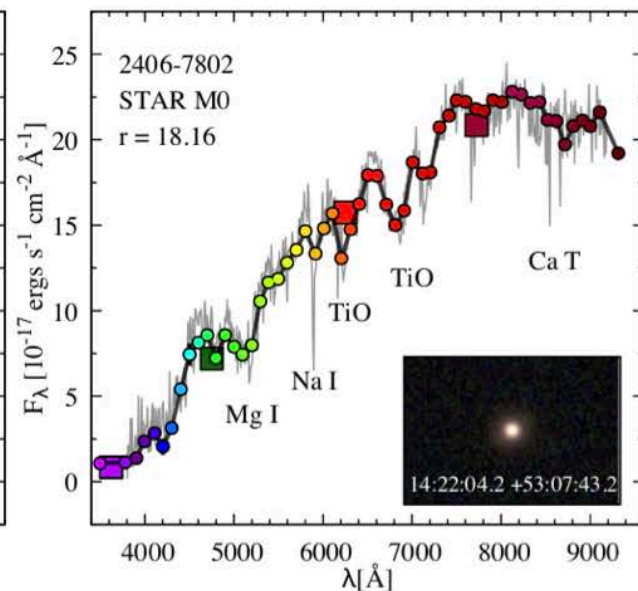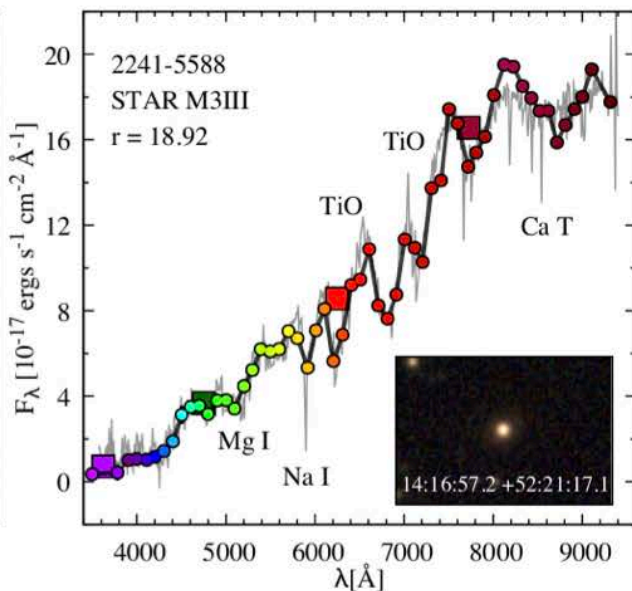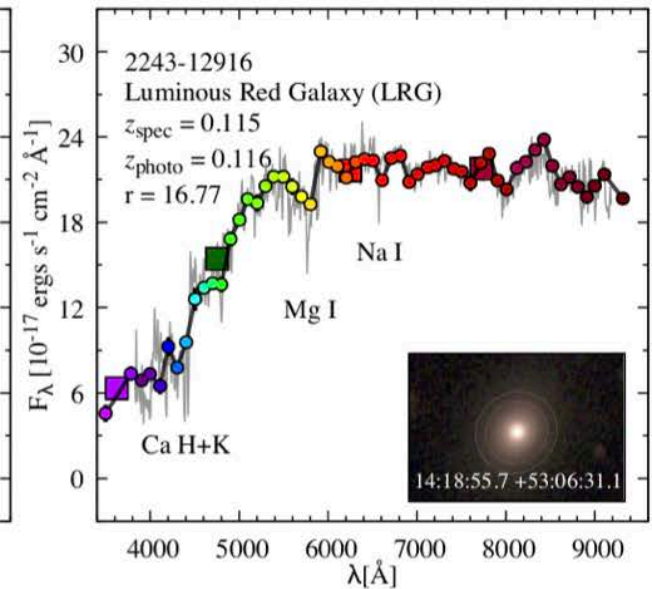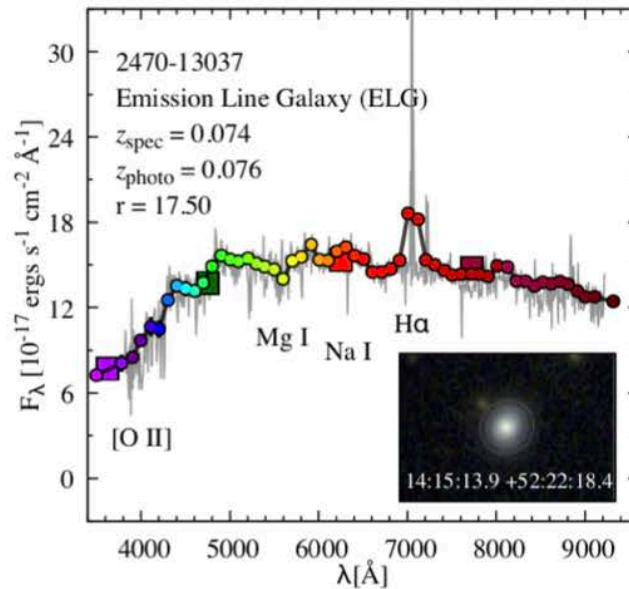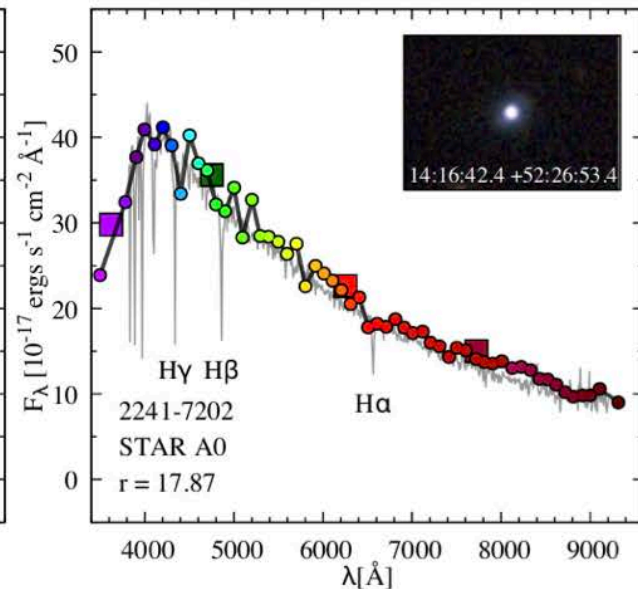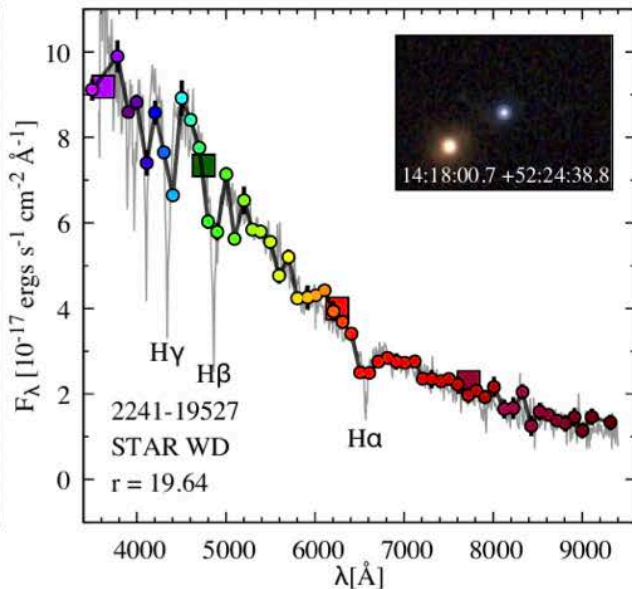
z_spec=0.244   z_phot=0.246

J-PAS reality

ideal J-PAS   *perturbed* J-PAS   *ideal* J-PAS   *perturbed* J-PAS
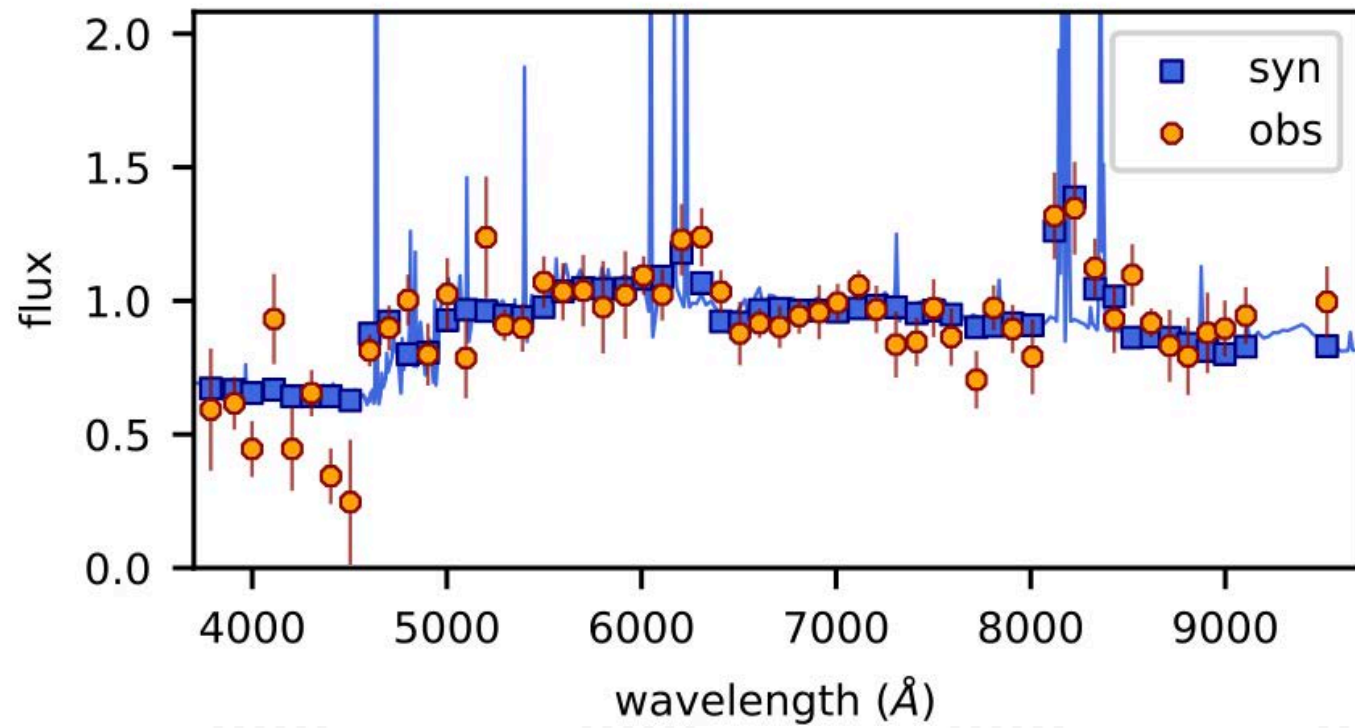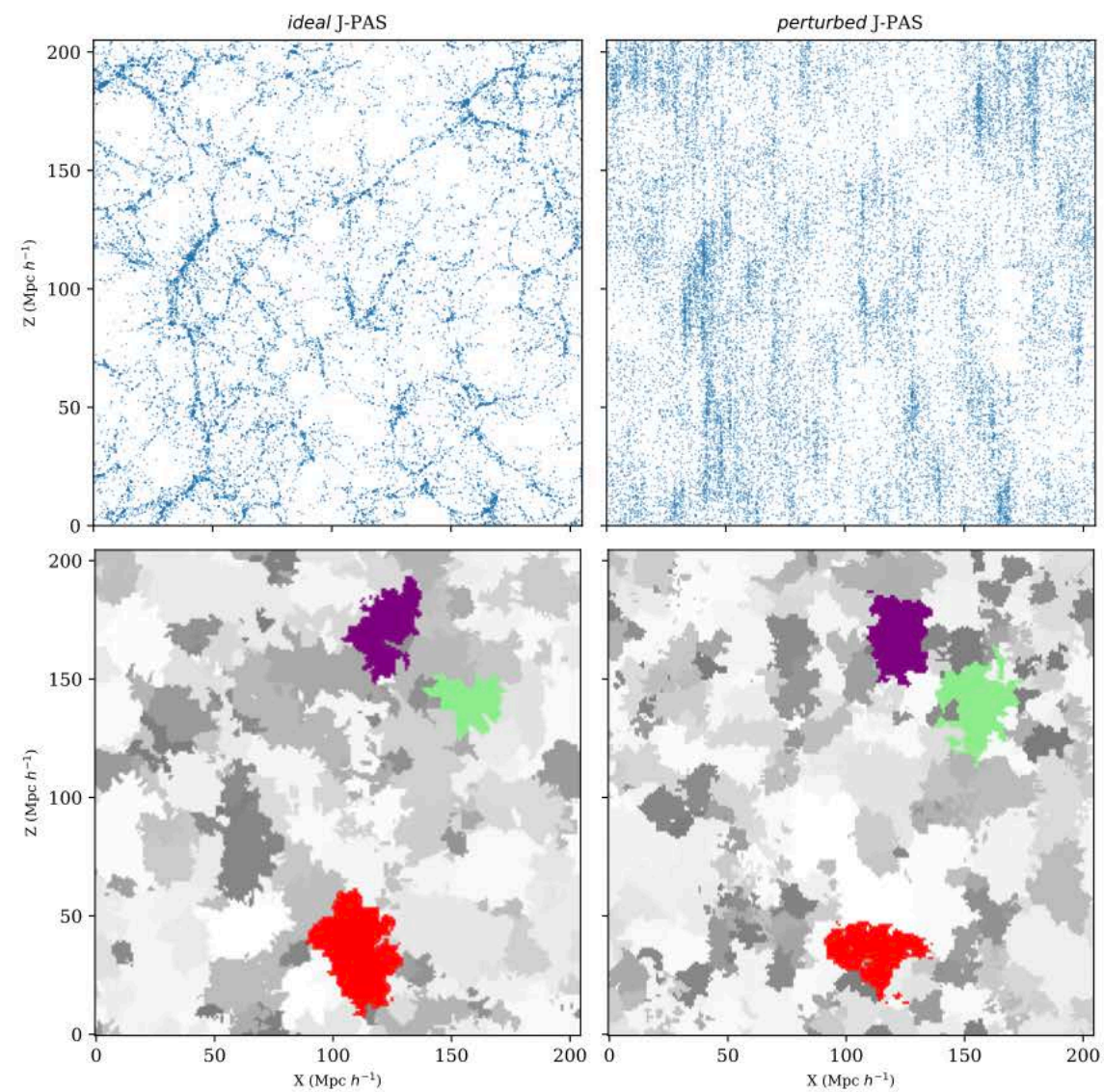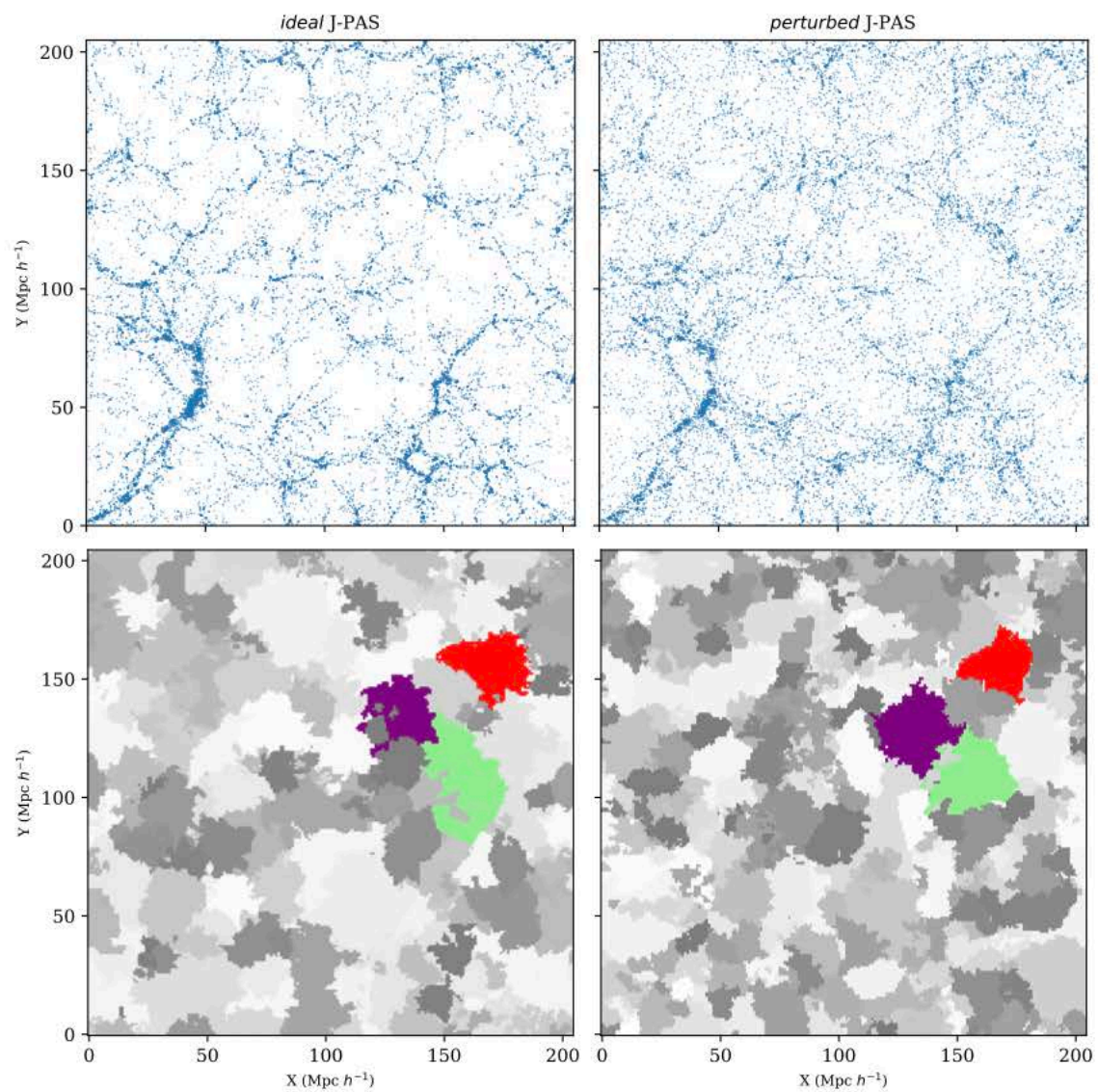
Measuring distances - photometric redshifts
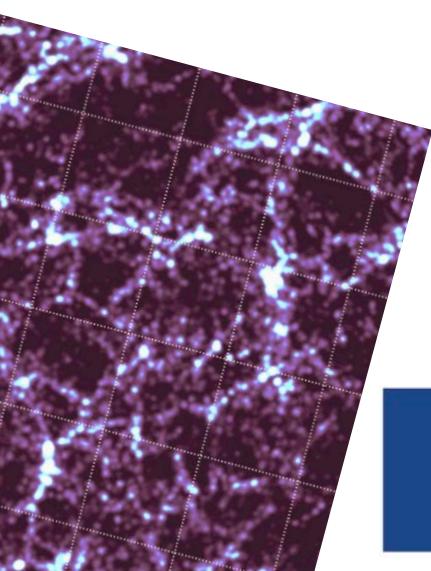
$$p(\zeta \mid F, m_0) = \sum_{T \in \mathbf{T}} p(\zeta, T \mid F, m_0) \propto \sum_{T \in \mathbf{T}} p(\zeta, T \mid m_0) p(F \mid \zeta, T), \quad (1)$$

$$p(F \mid \zeta, T) \propto \frac{1}{\sqrt{F_{TT}}} \exp\left[-\frac{\chi^2(\zeta, T, a_m)}{2}\right],$$

$$F_{T\alpha} = \frac{\int f_{T,\zeta}(\lambda) W_\alpha(\lambda)\, d\lambda}{\int W_\alpha(\lambda)\, d\lambda},$$
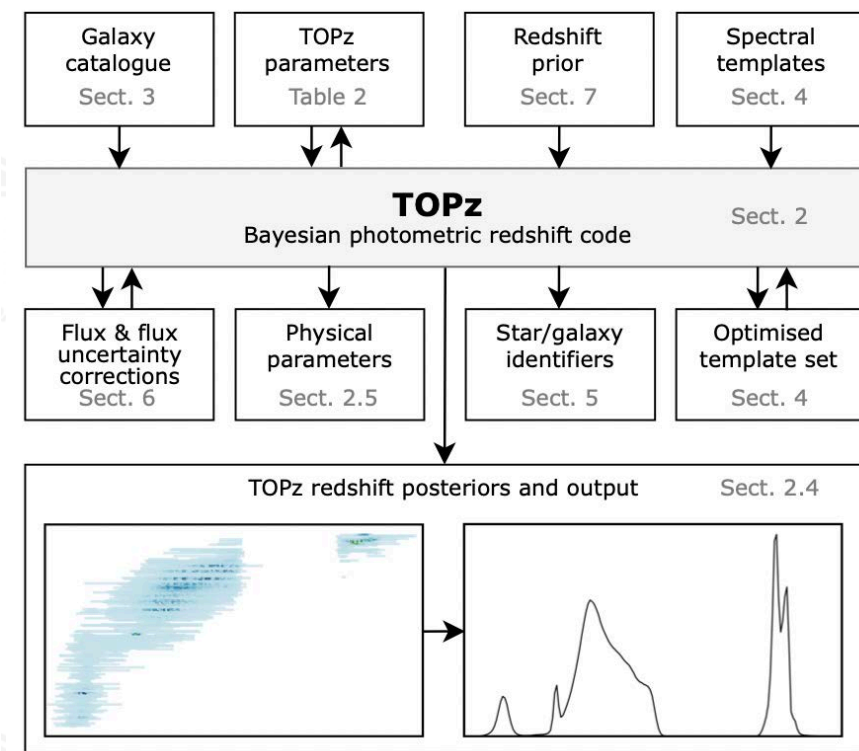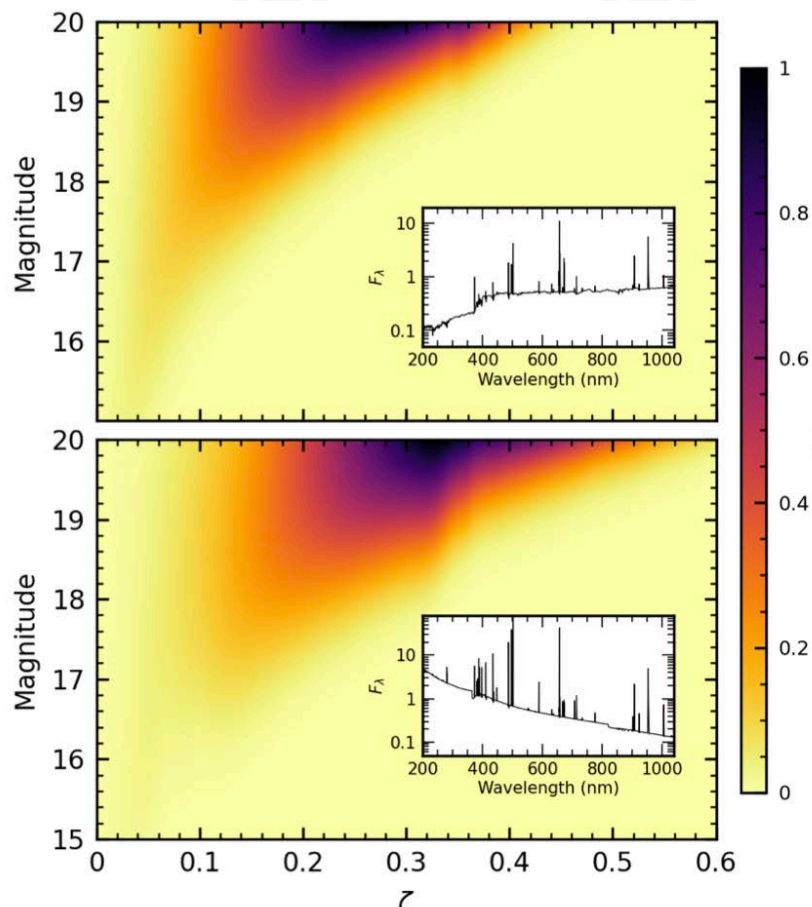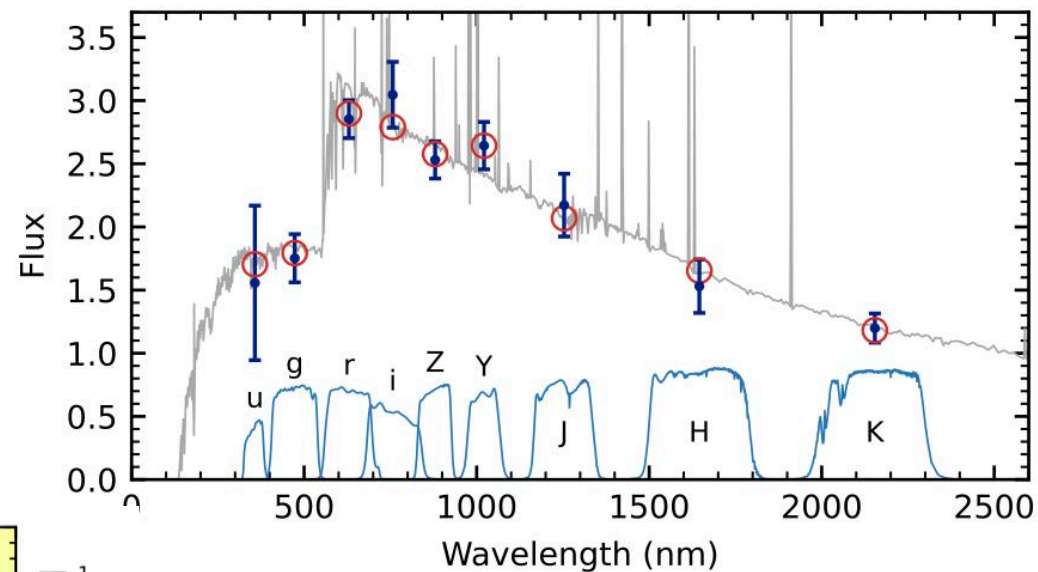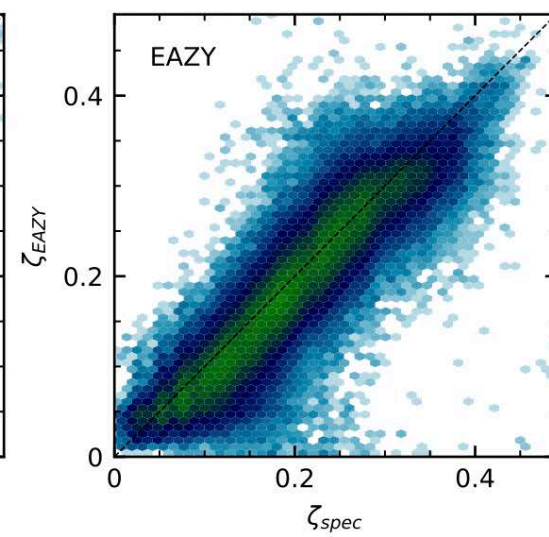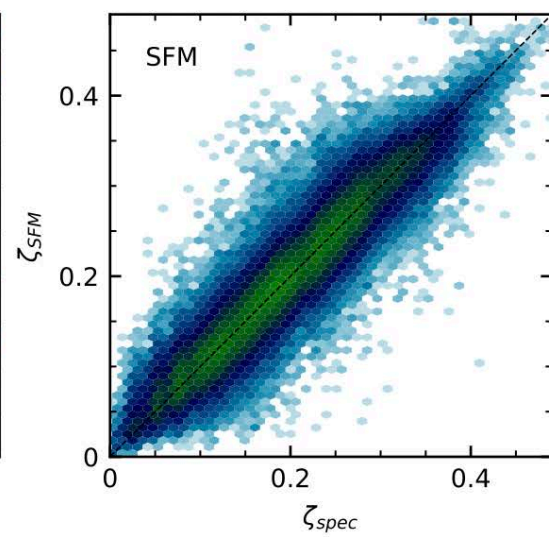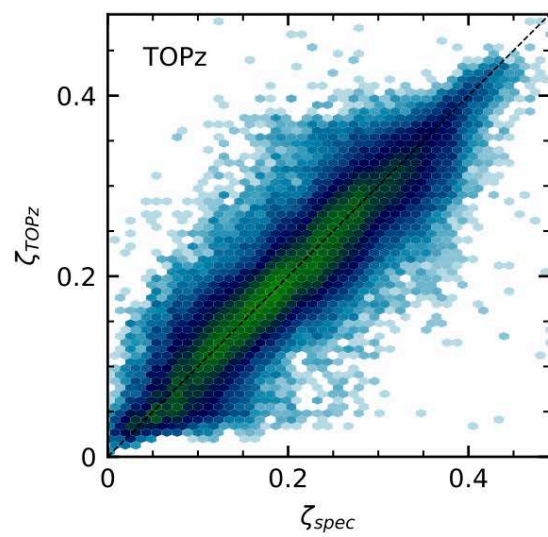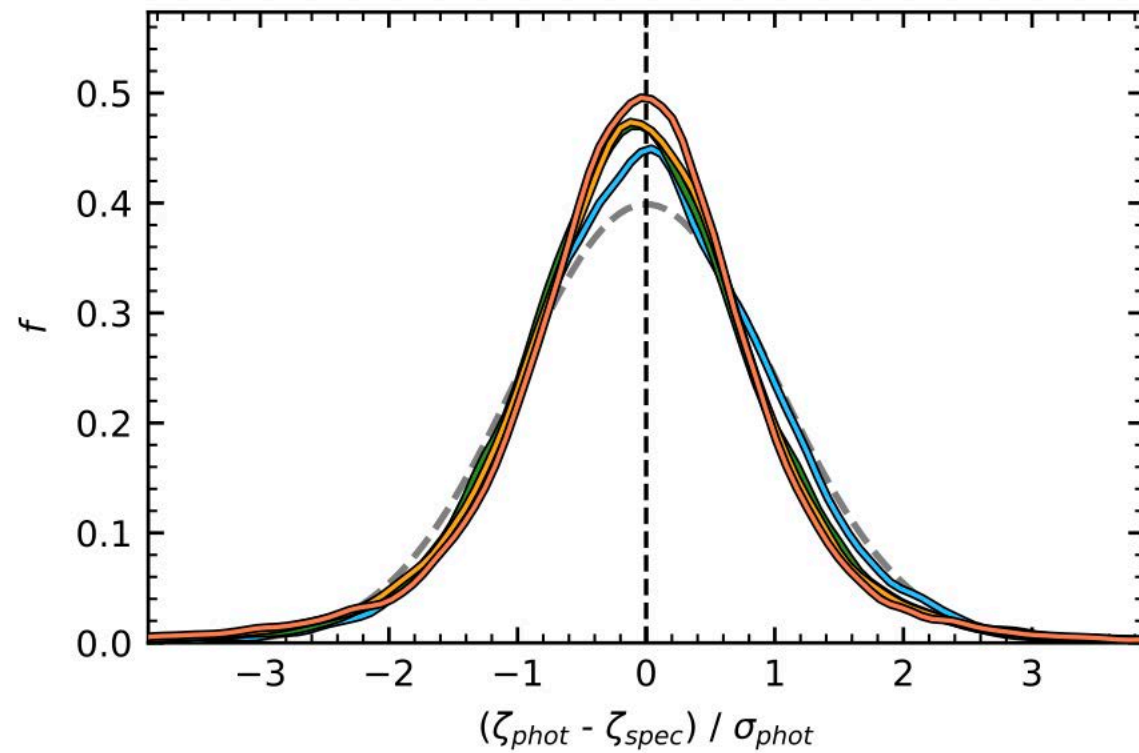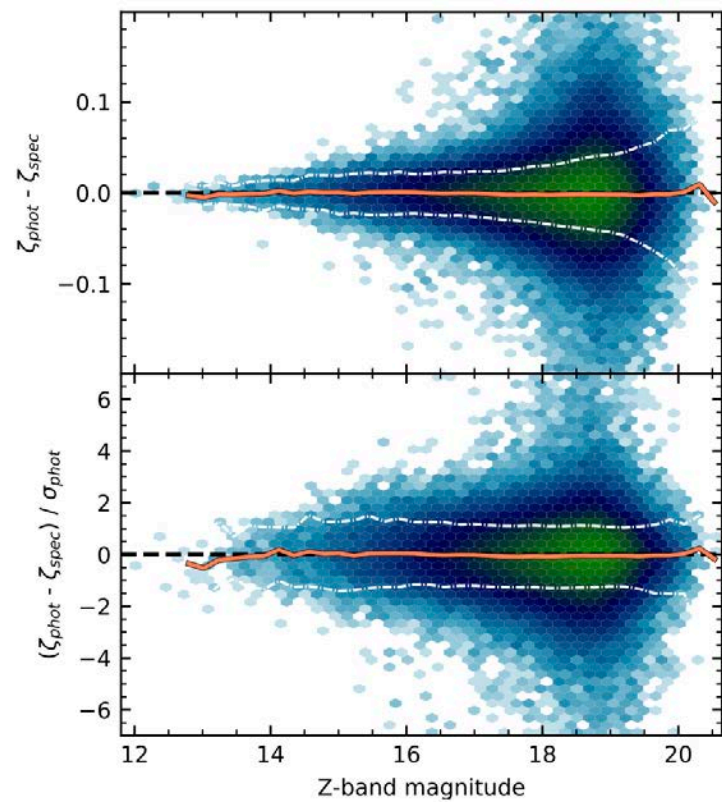
J-PAS — Javalambre Physics of the Accelerating Universe Astrophysical Survey
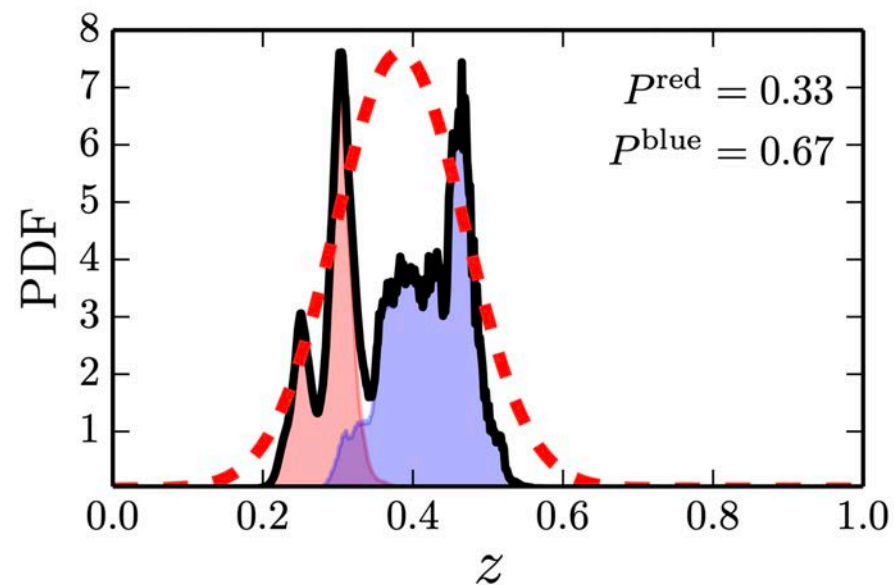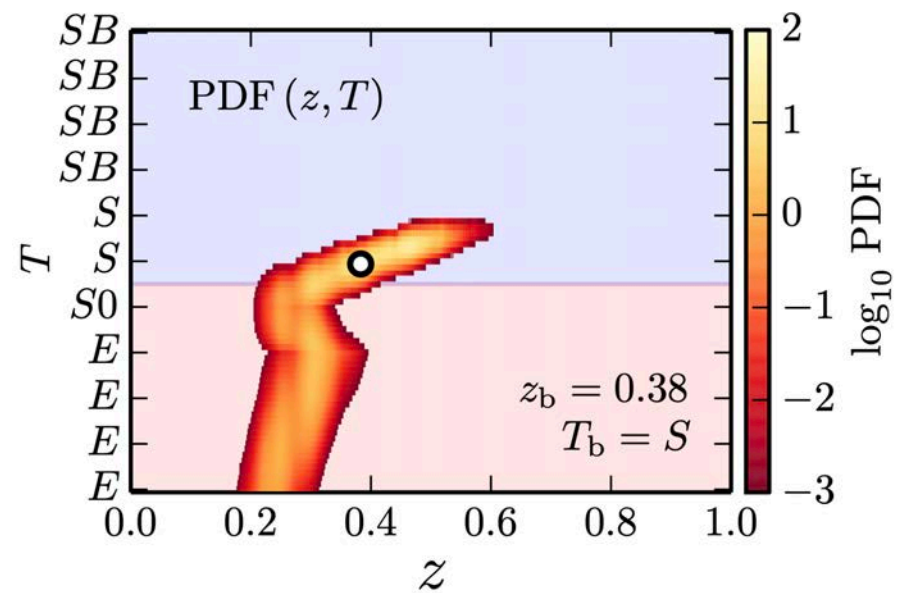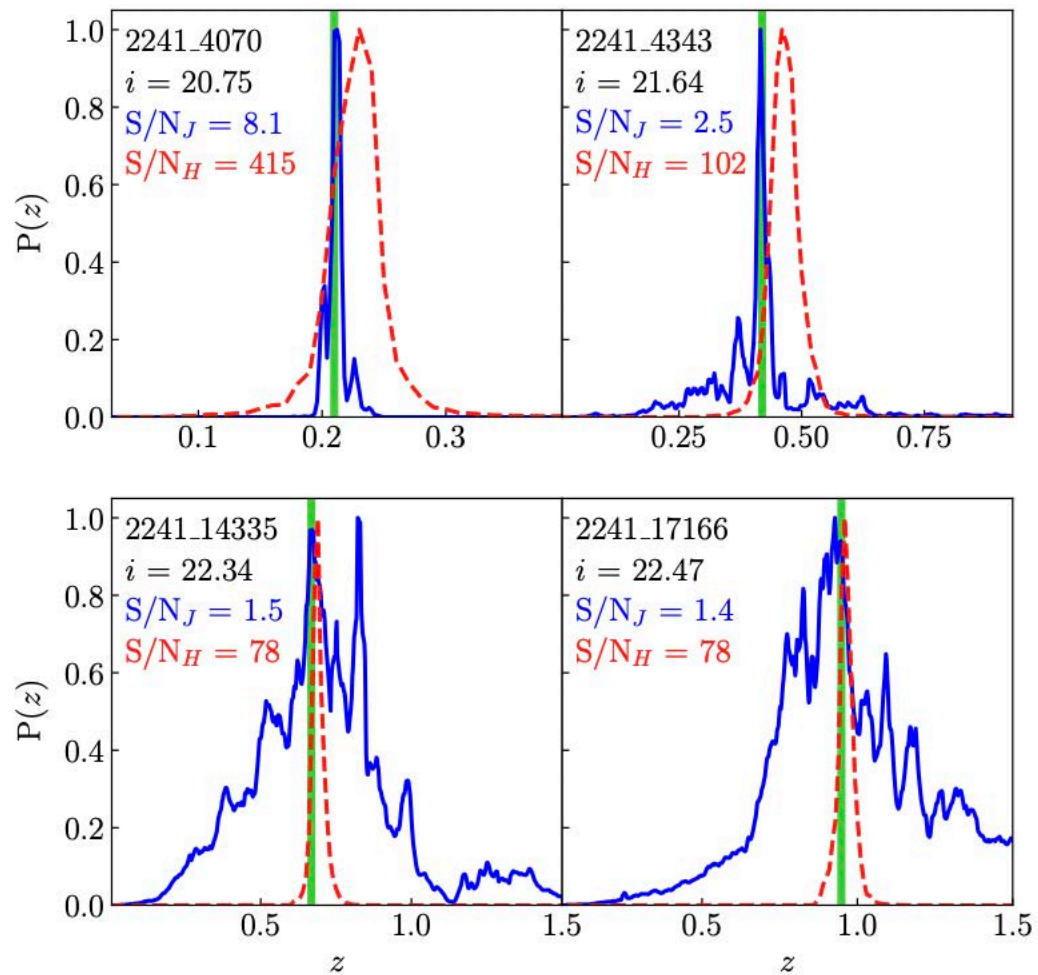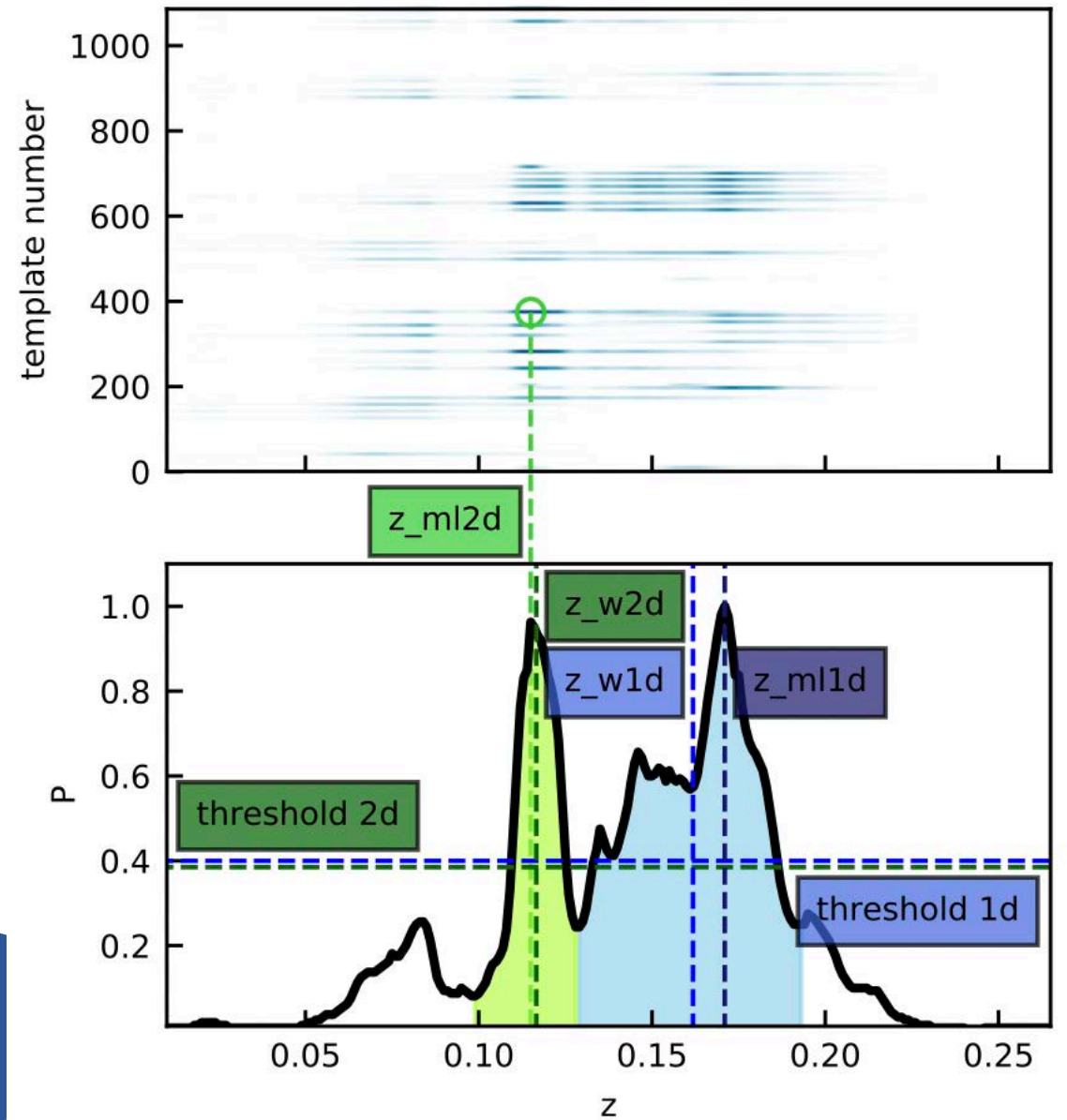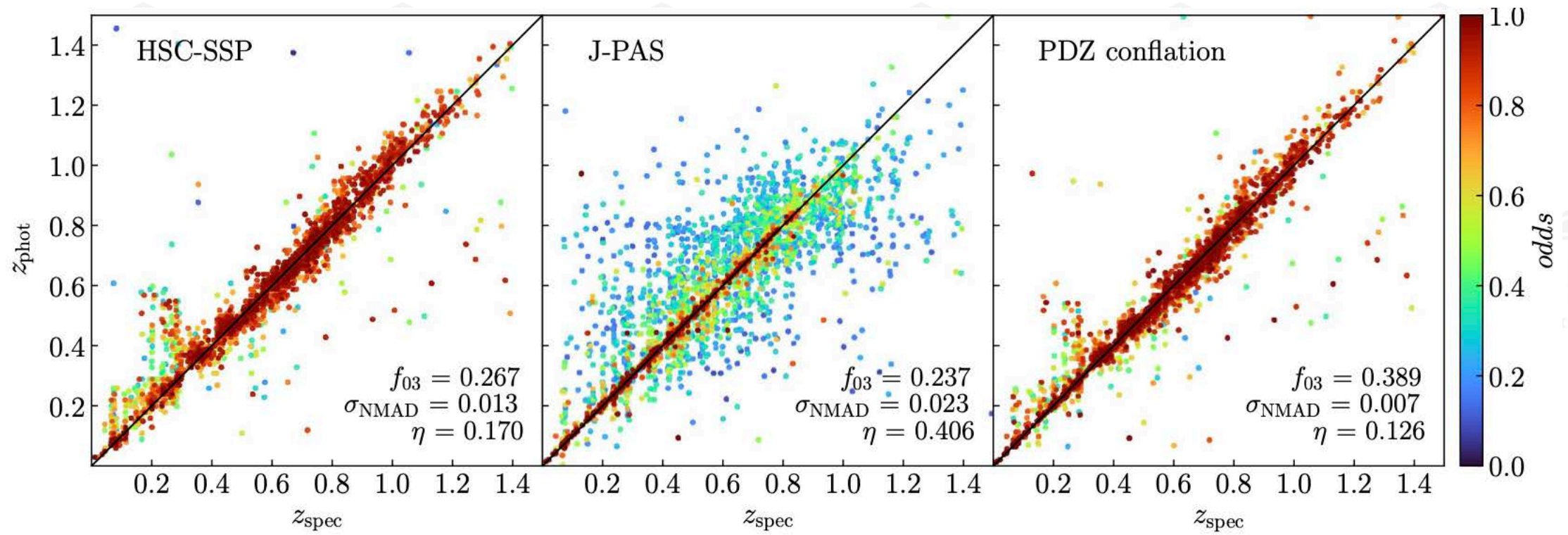
J_PAS

J_PAS
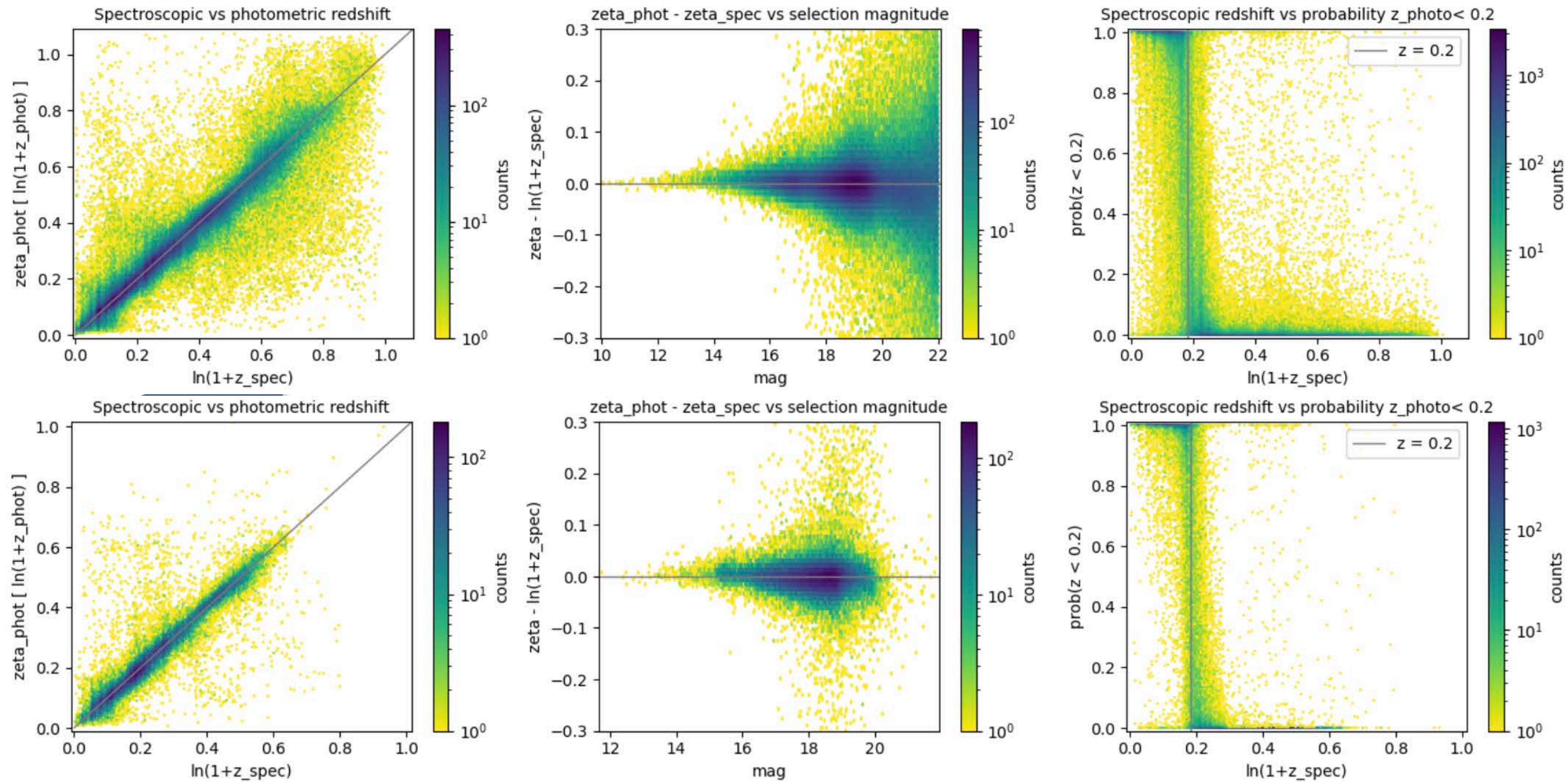
WAVES North: with prior

Extra slides

UNIVERSITY OF TARTU
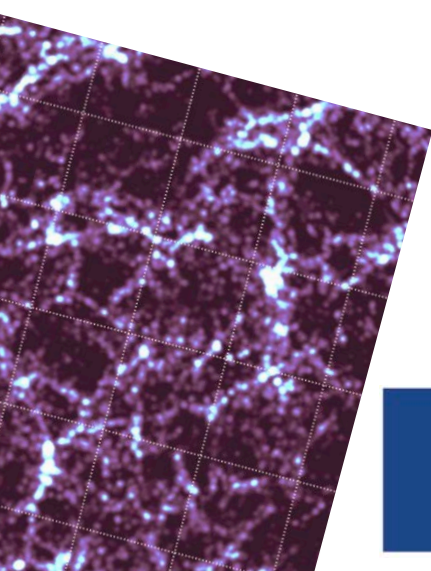
Is this the same galaxy?
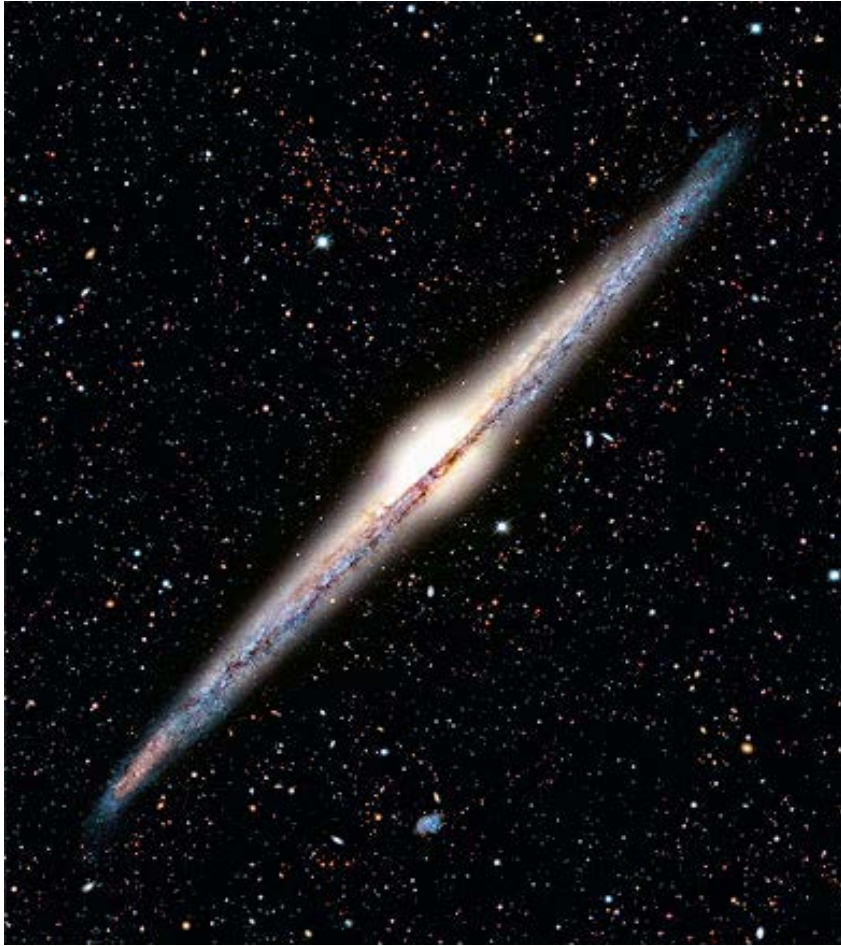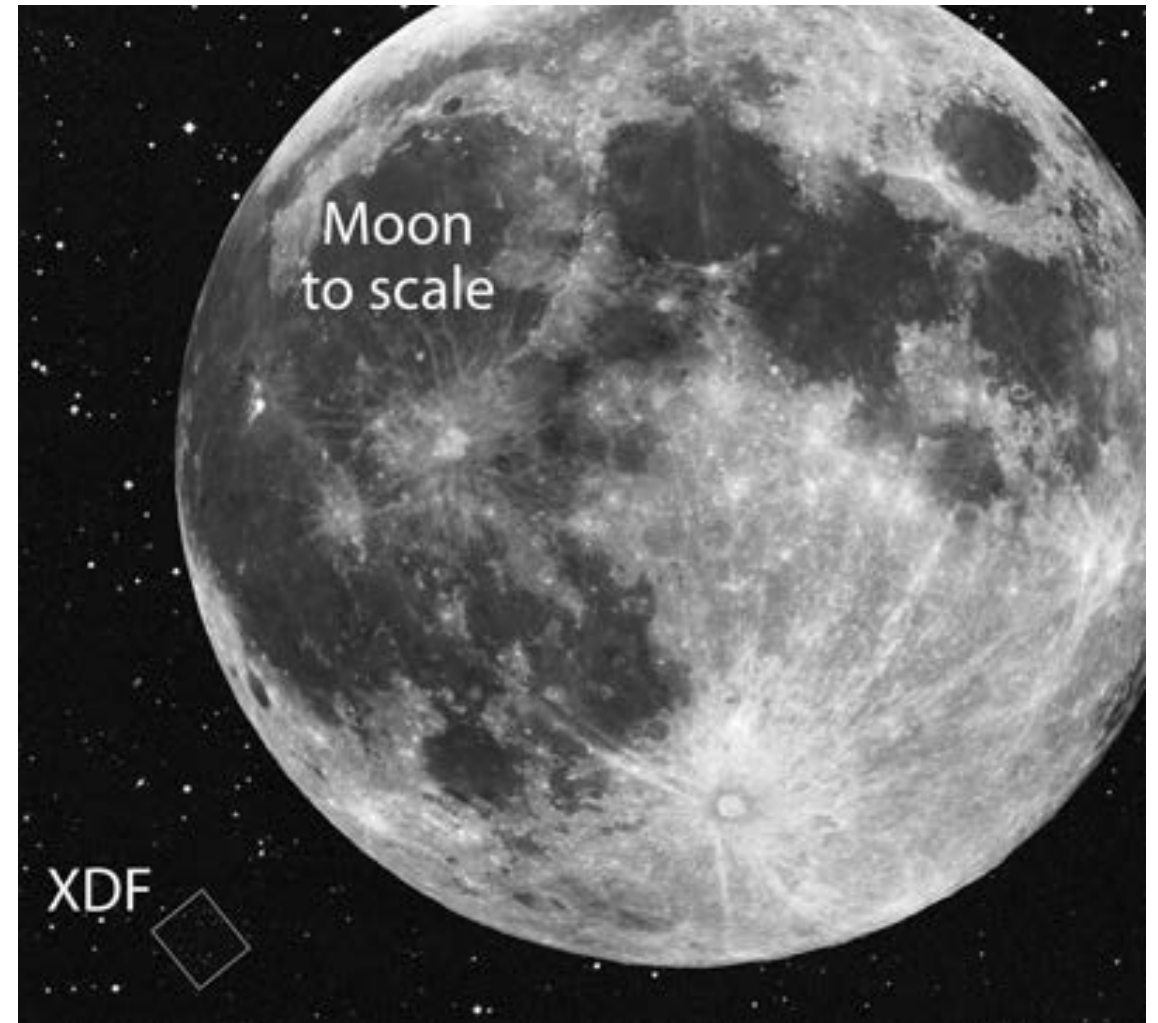
How empty is Univesre?
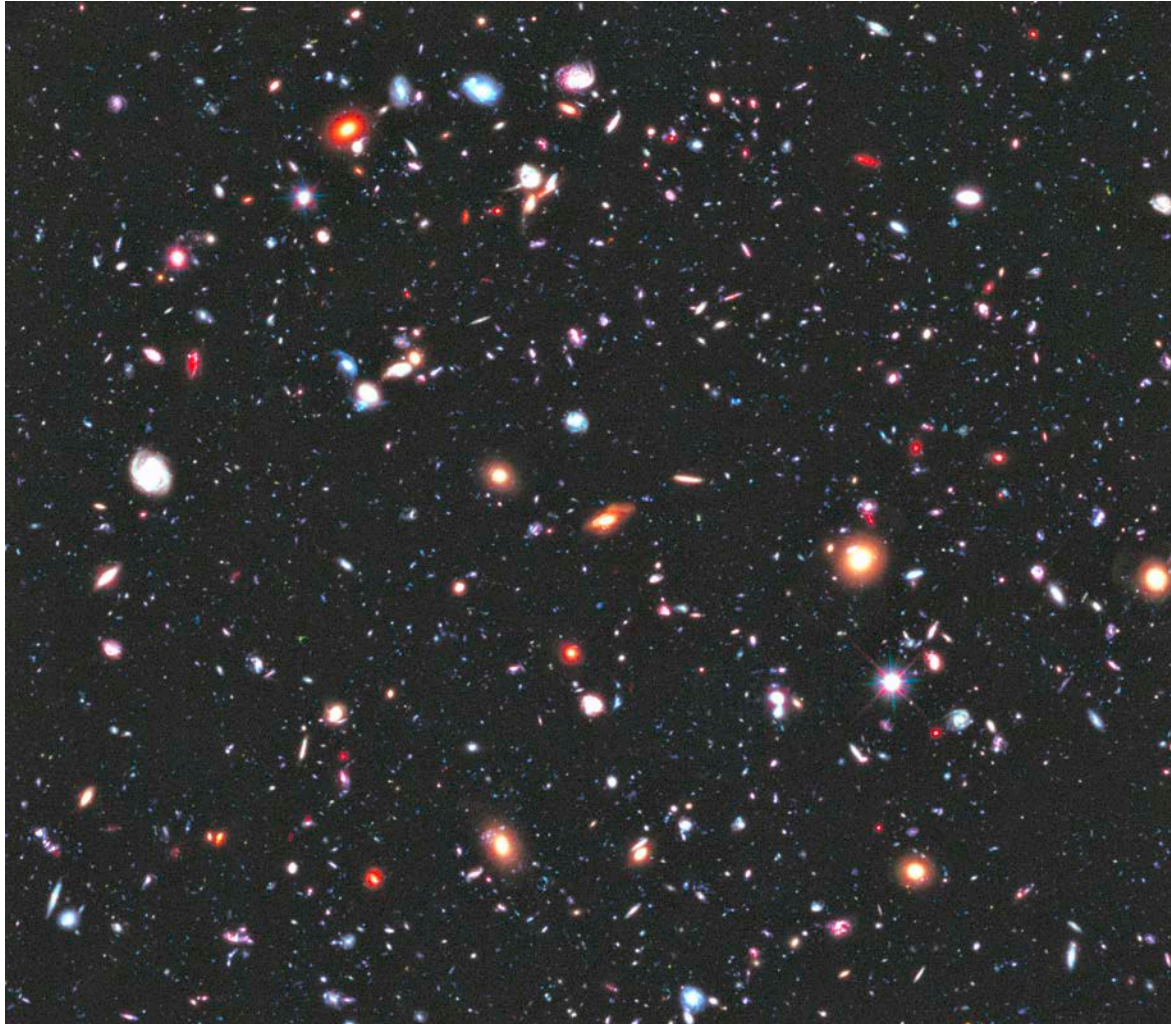
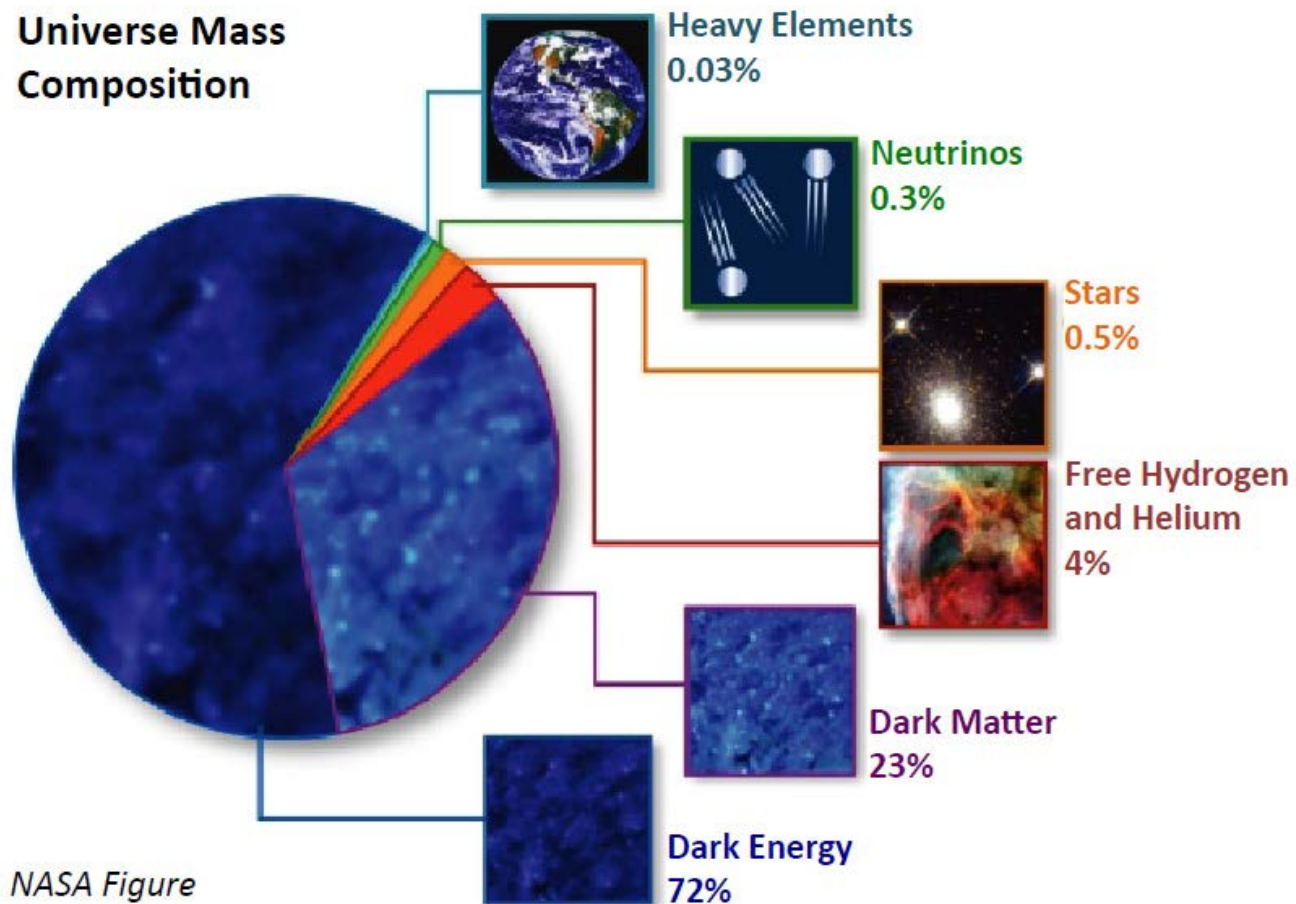Source: ESA/Hubble
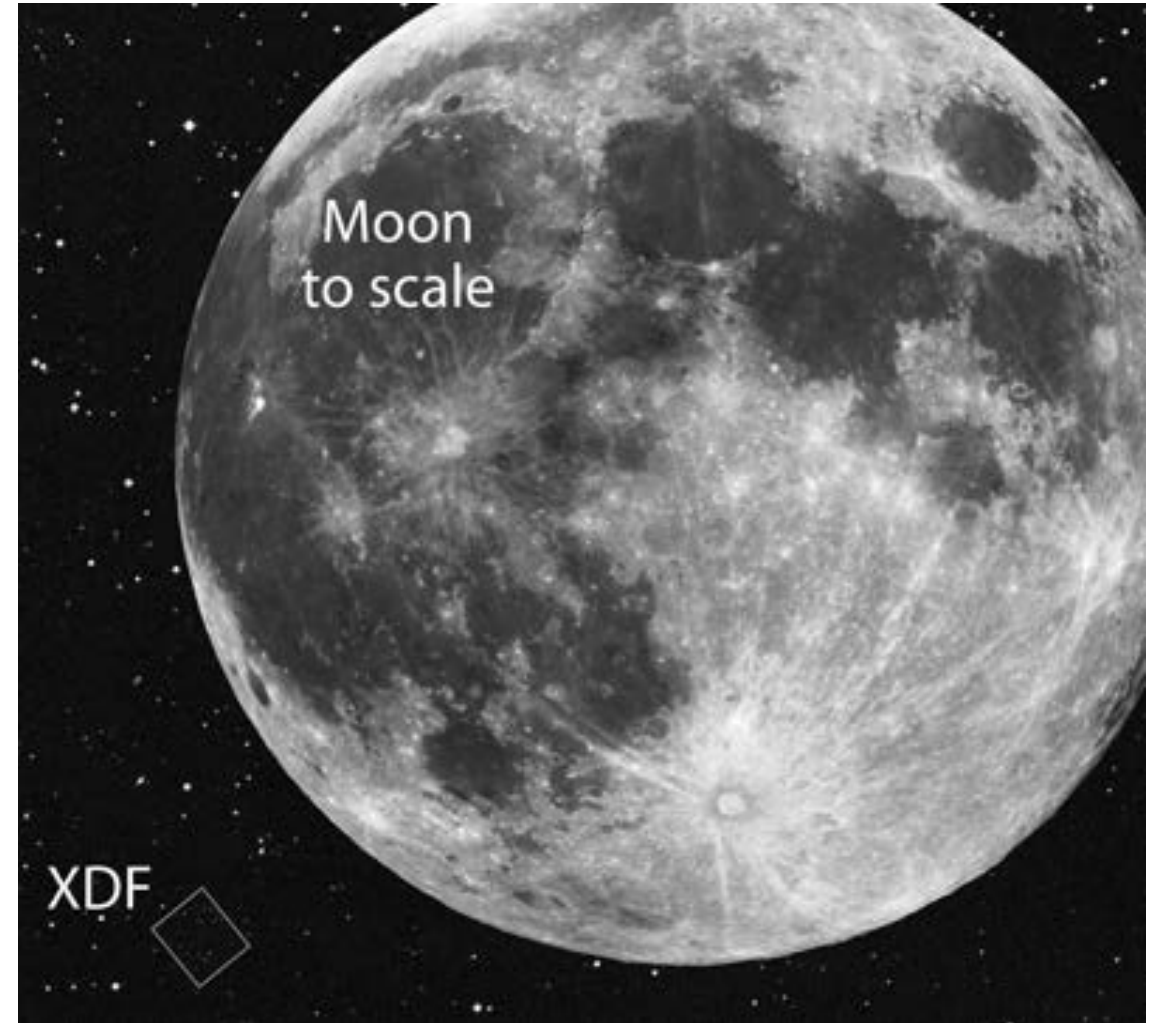
The Origin of the Solar System Elements

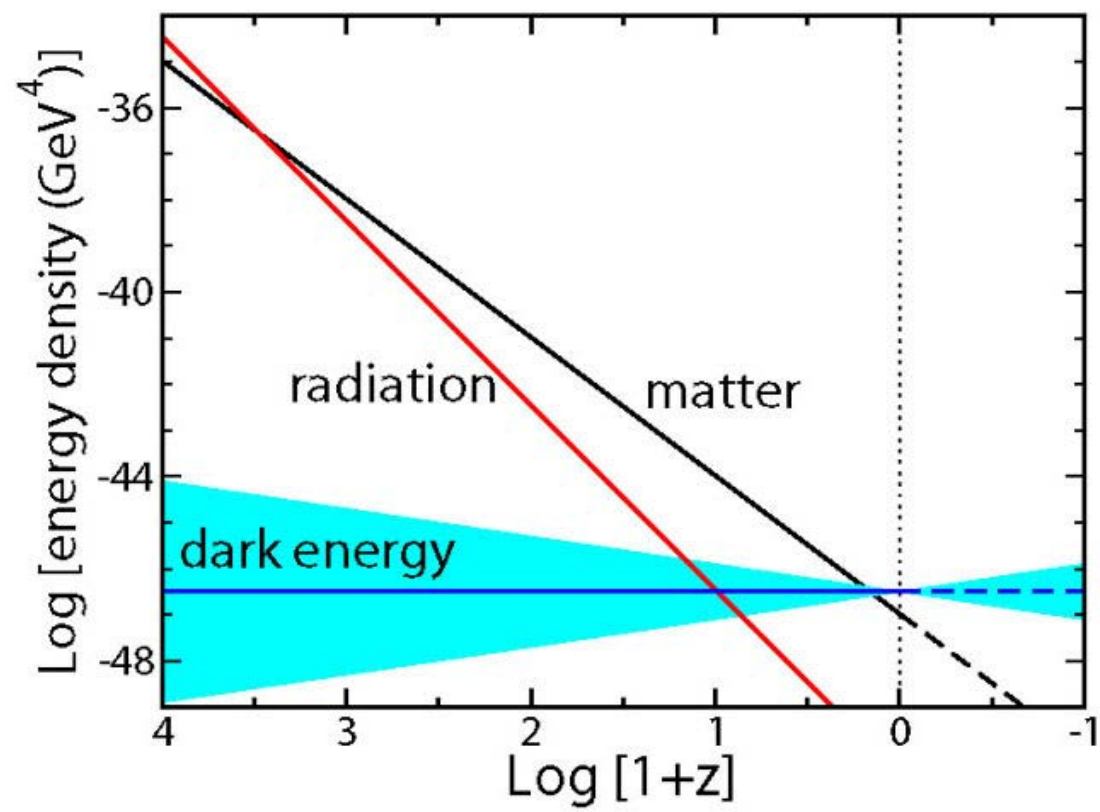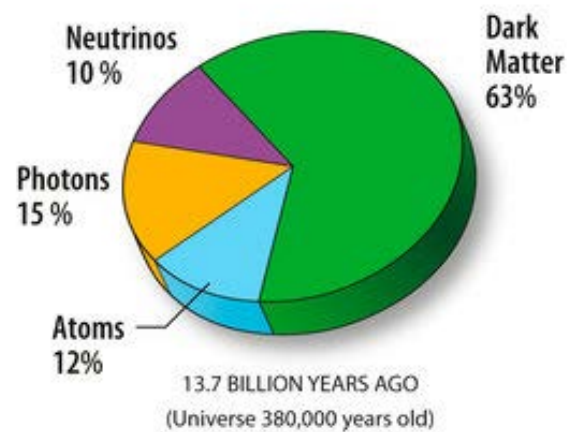Graphic created by Jennifer Johnson

Astronomical Image Credits: ESA/NASA/AASNova

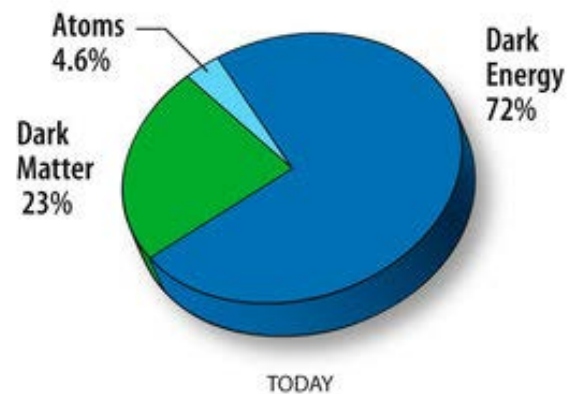# How dark is the Universe?
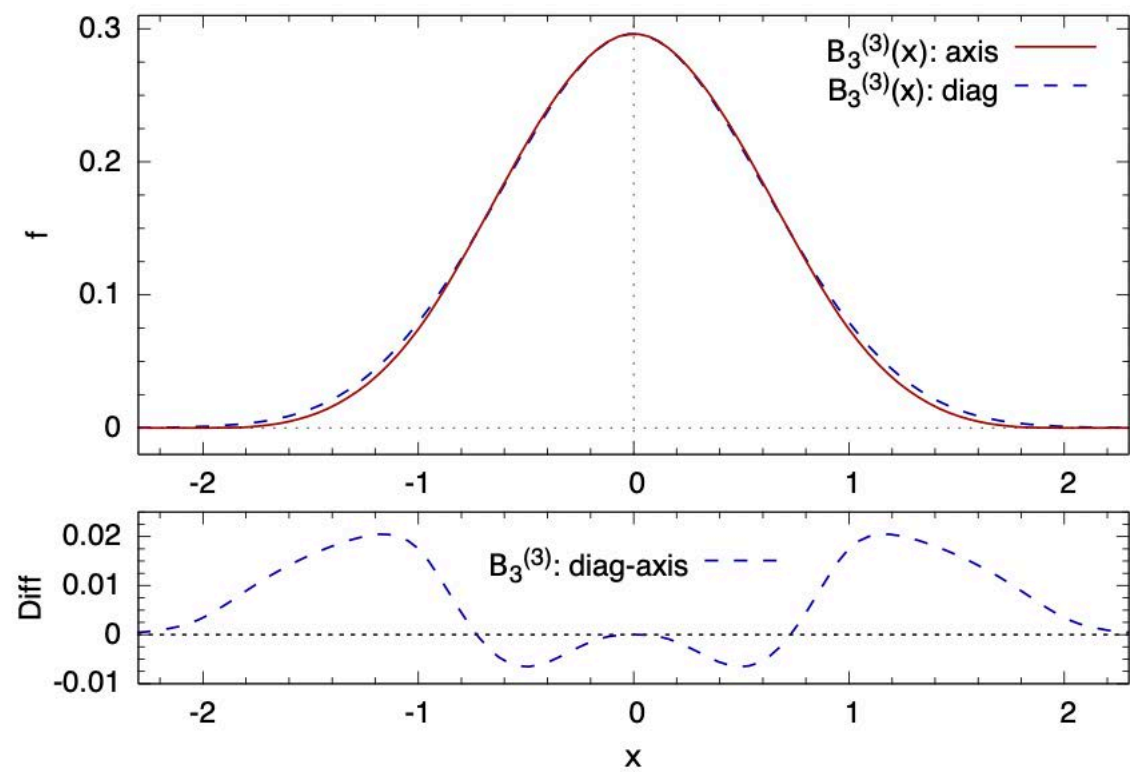

Universe Mass Composition

- Heavy Elements 0.03%
- Neutrinos 0.3%
- Stars 0.5%
- Free Hydrogen and Helium 4%
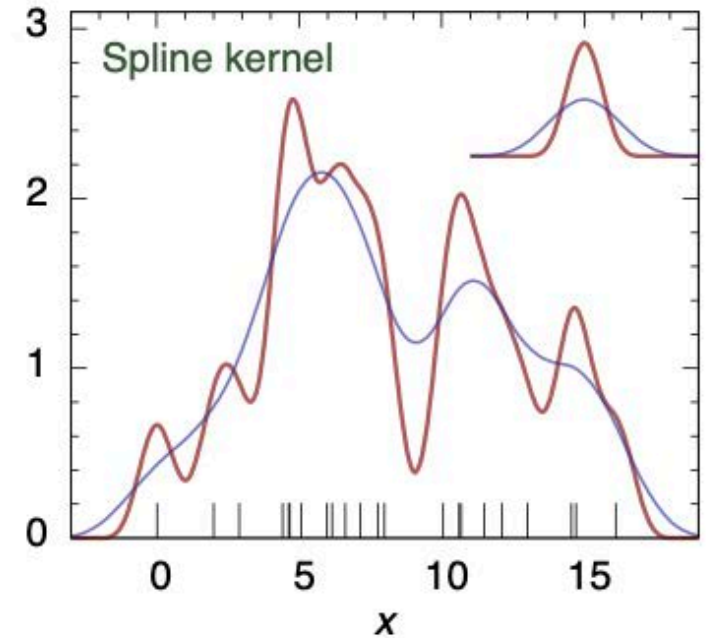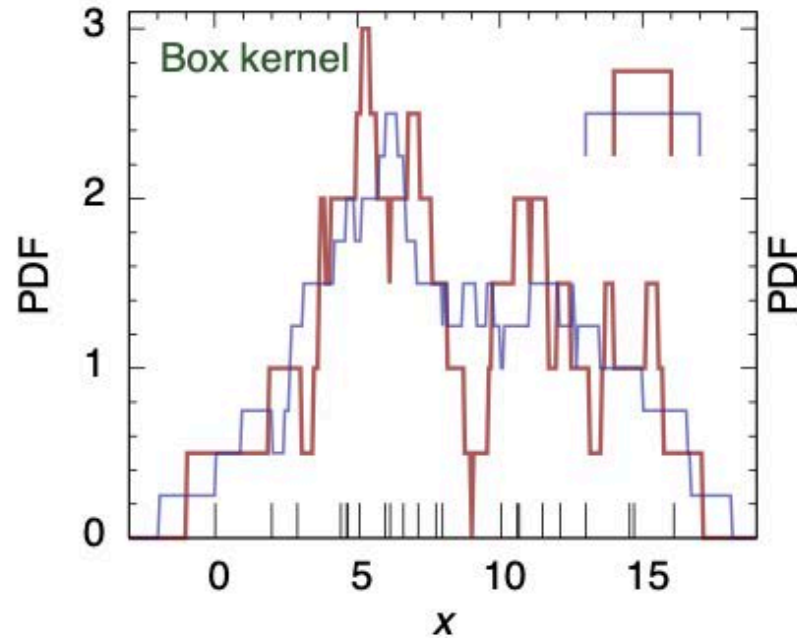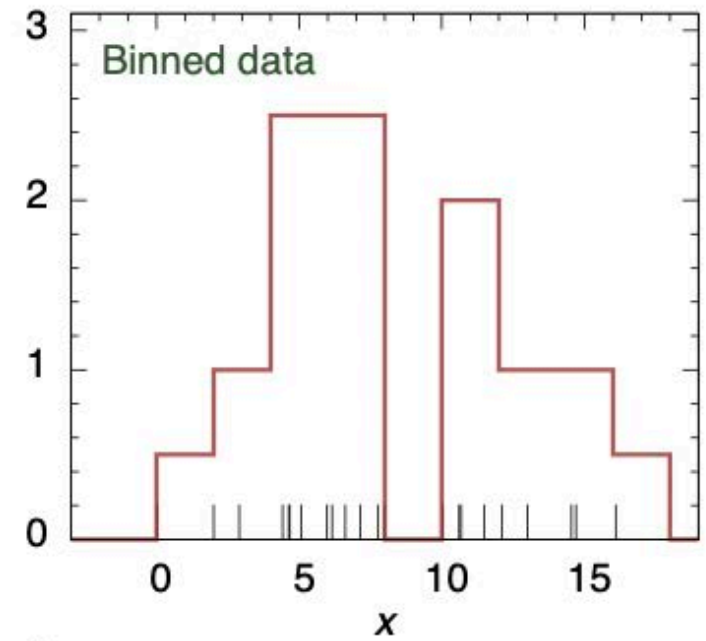- Dark Matter 23%
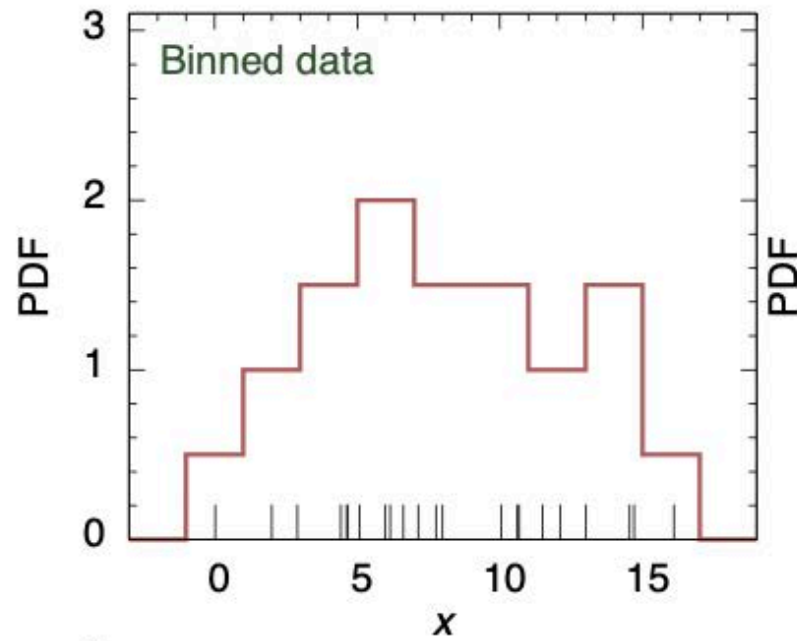- Dark Energy 72%

NASA Figure

How dark is the Universe?

$$B_3(x) = \frac{|x-2|^3 - 4|x-1|^3 + 6|x|^3 - 4|x+1|^3 + |x+2|^3}{12}.$$

Distributions

Random part of the sky