Filamentary Environment and Mass Measurements of Galaxy Clusters

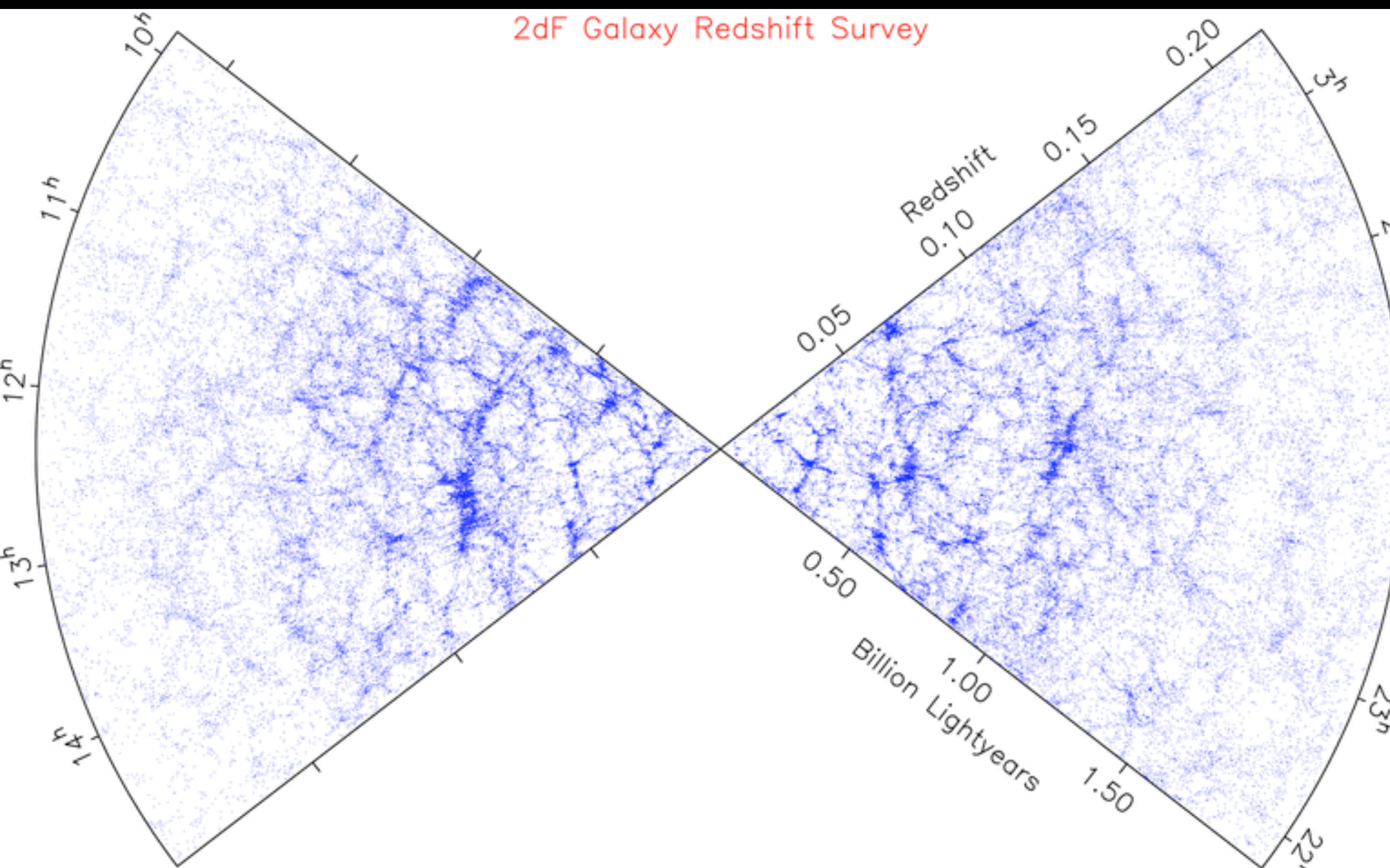
Yookyung Noh (UC Berkeley)

work with Joanne Cohn

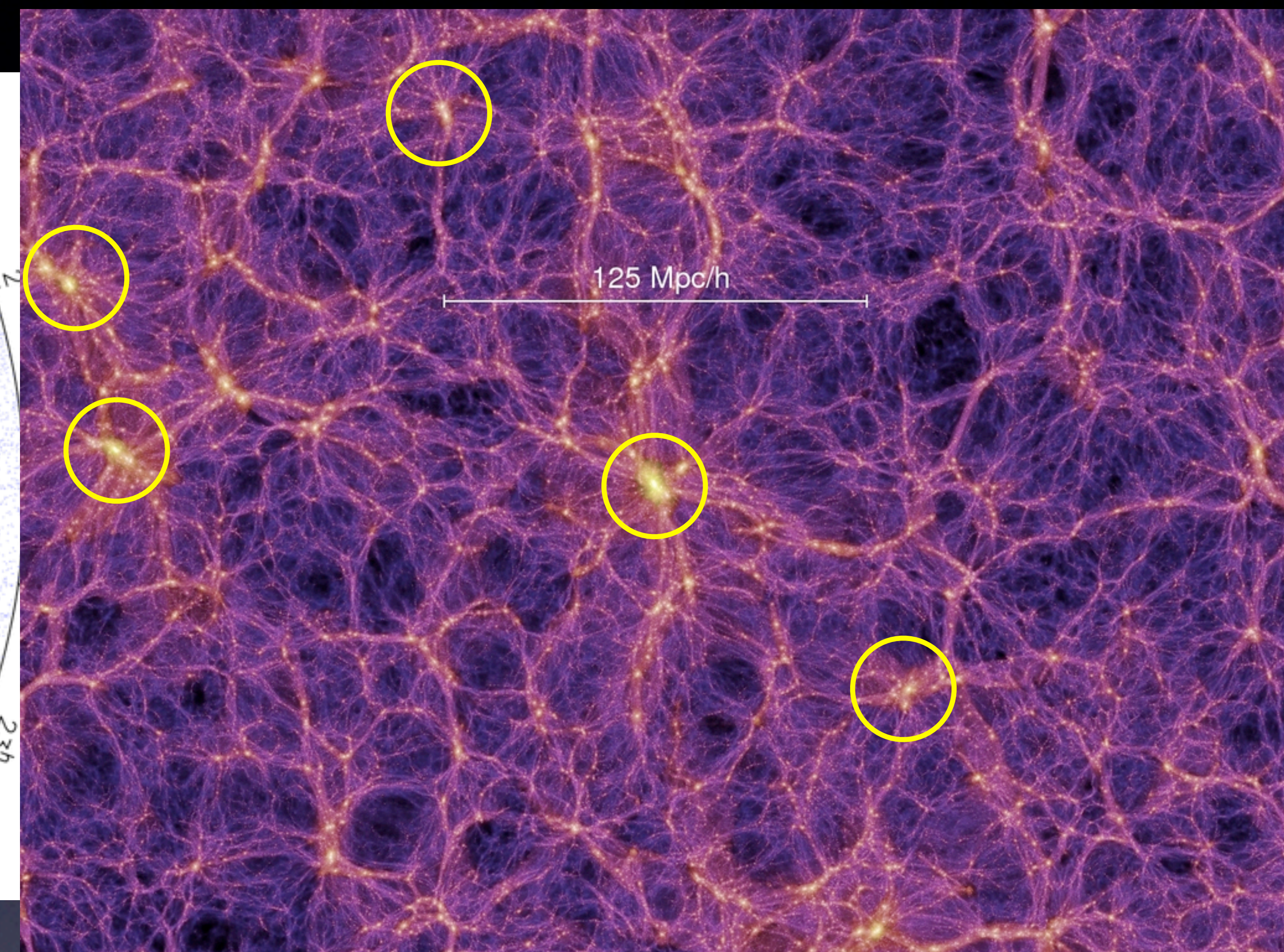
12/10/2012

Fermilab Particle Astrophysics Seminar

Cosmic Web



In observed galaxies



In simulated dark matter

Clusters are the largest, most massive virialized objects lying at the nodes of cosmic web

($M \approx 10^{14}$-10^{15} $M_{\odot}/h$, $R \approx 1$ Mpc)

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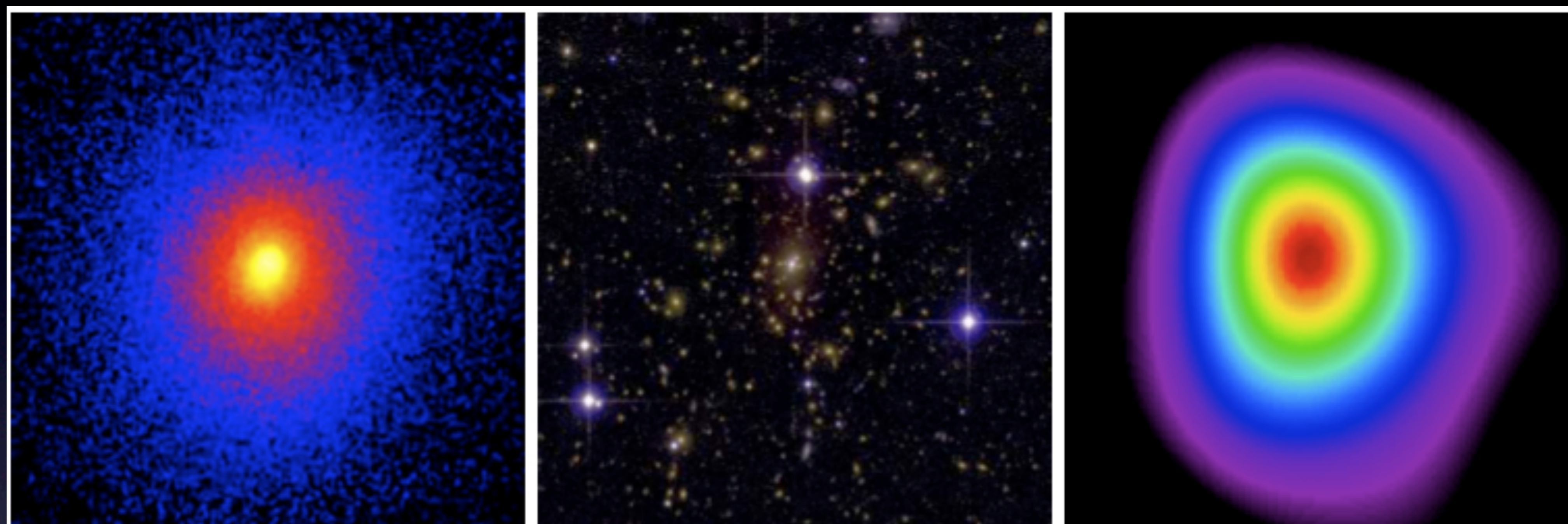
Clusters in Multi-wavelength Observations

Abell 1835
z=0.25
5.2 arcmin
(~1.2Mpc)
M~10^{15} $M_\odot$



Mantz
Linden++
Marrone

X-ray
Luminous, spatially extended objects due to hot gas

Optical
Large populations of galaxies

Microwave
Sunyaev-Zeldovich Effect (SZE)

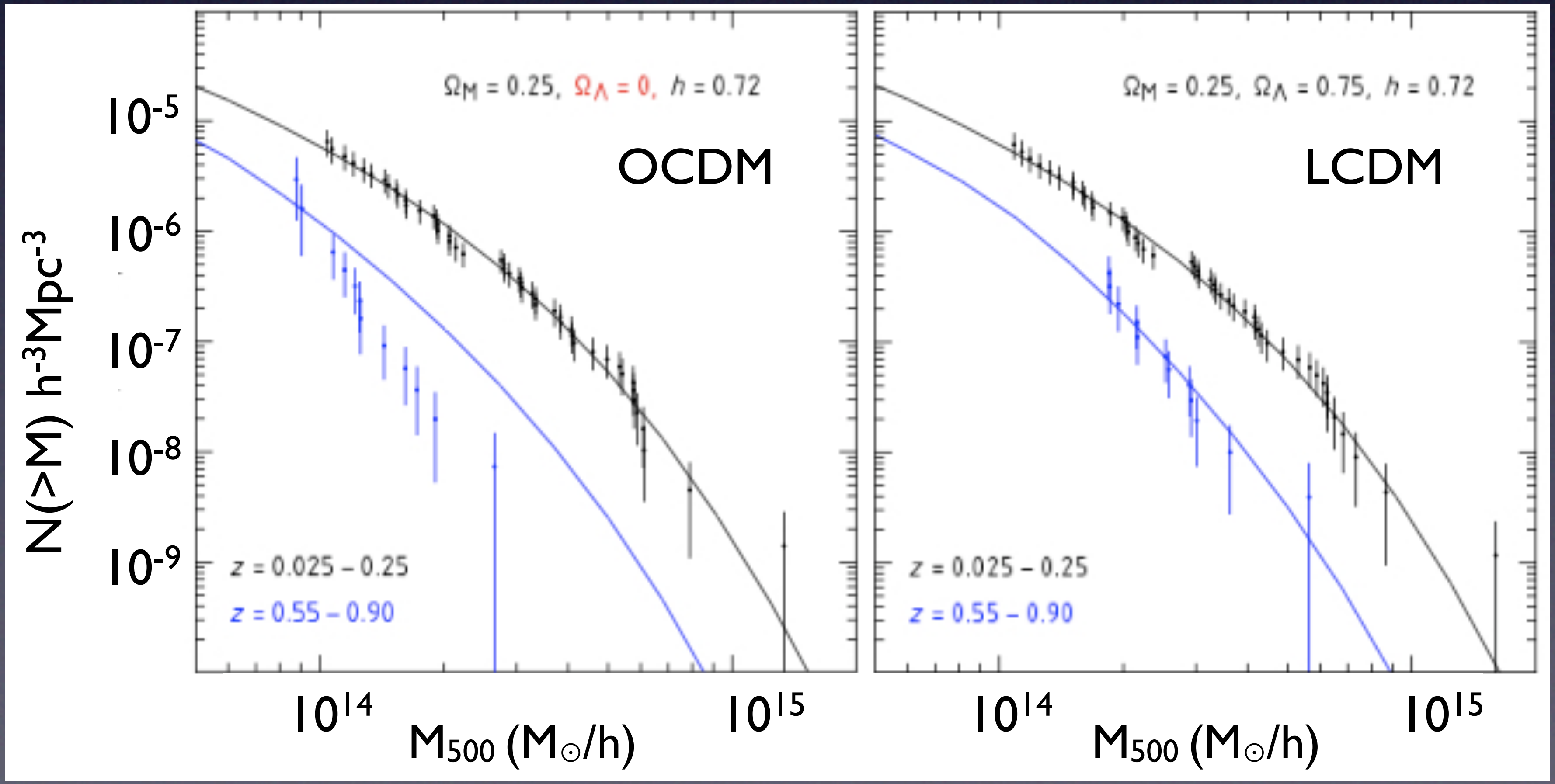
Decrement or increment of the background CMB

Why do we study clusters?

- Cosmological probe
- Special environment of galaxies
- Hosting extreme astrophysical phenomena

Voit 05,
Allen++11, etc.

Example:

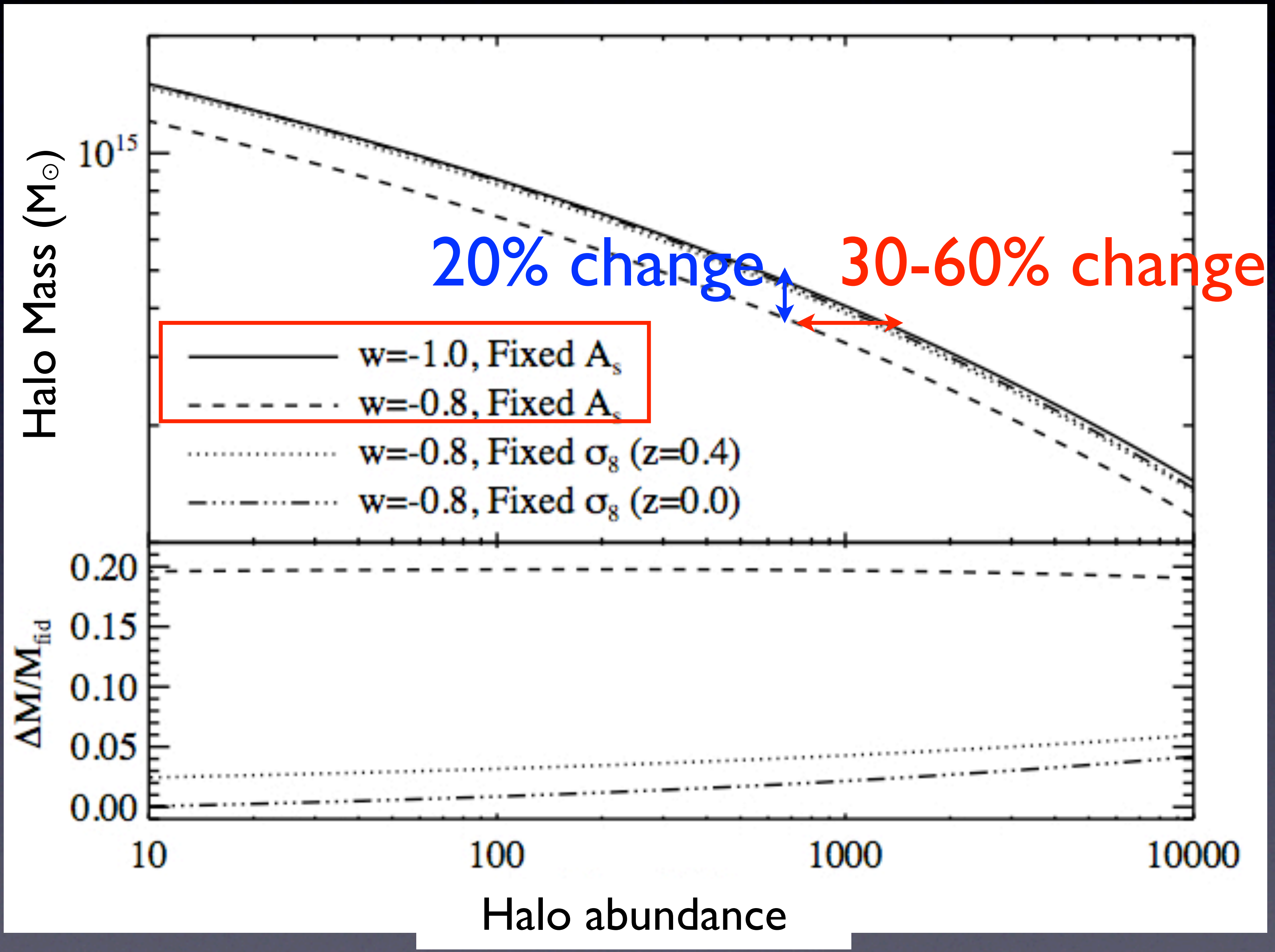


Vikhlinin++09

Cluster mass is a crucial property!

Change from w=-1 to w=-0.8

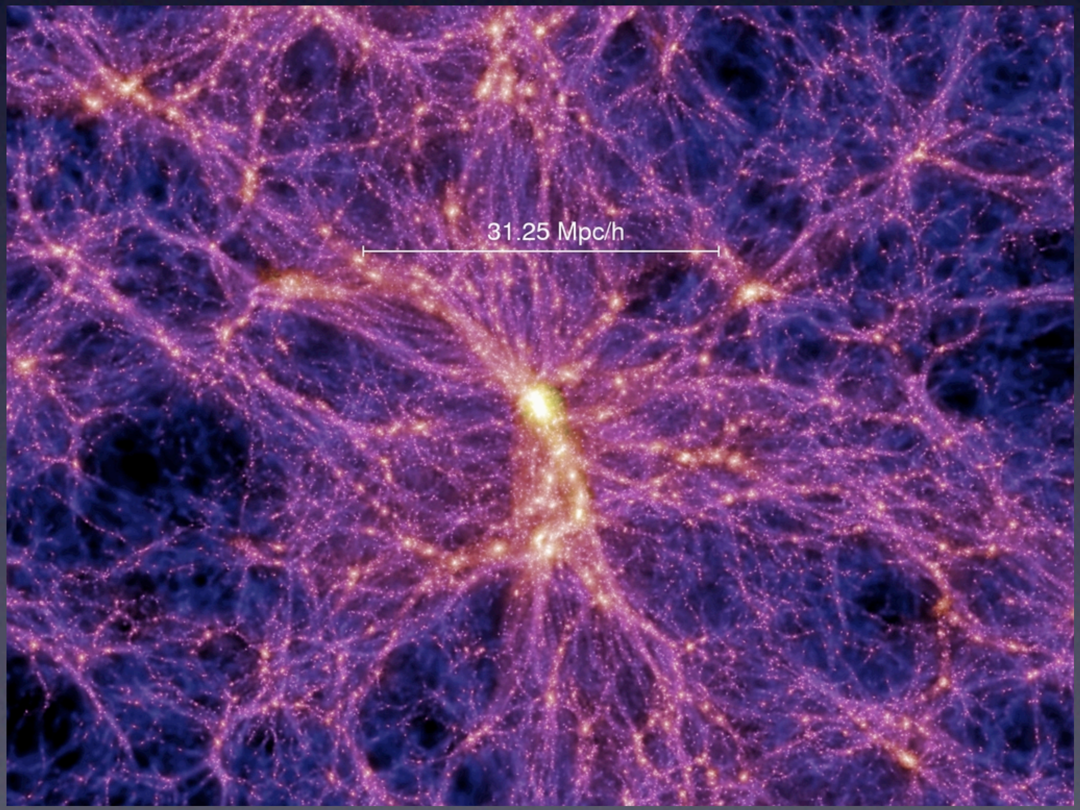
- 30-60% change in the predicted abundance
- only 20% change in the mass threshold



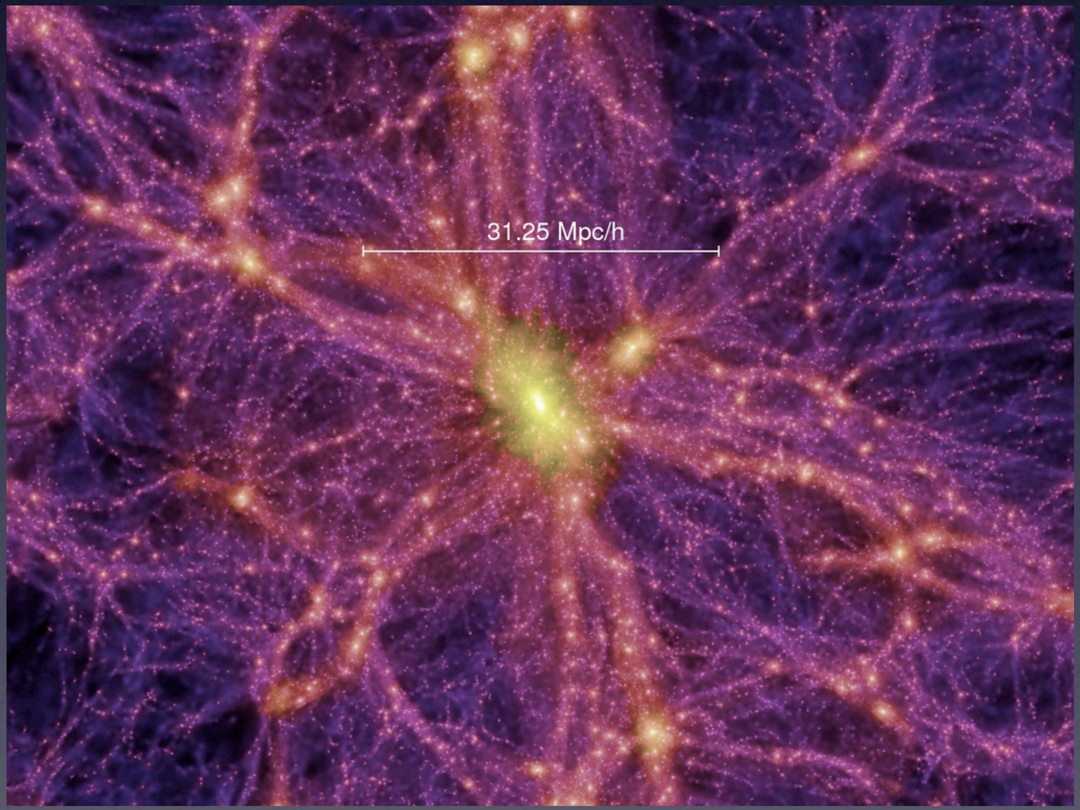
Weinberg++ 12

Challenges in Mass Measurements

- Measure cluster mass indirectly
- Measurements include the cosmic web around the cluster



z=1.4



z=0.0

millennium simulation

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Challenges in Mass Measurements

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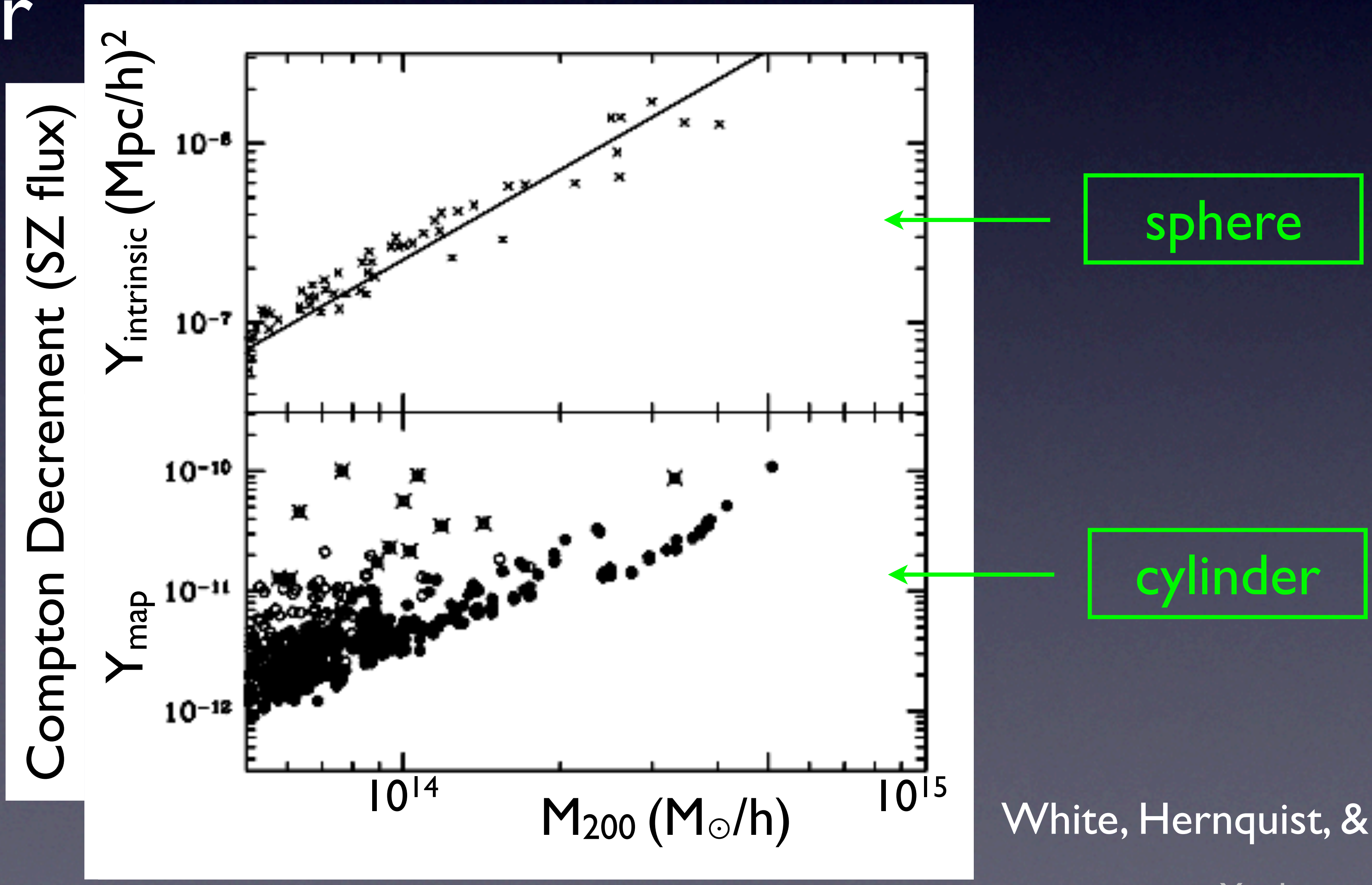
- Measurements include the cosmic web around the cluster



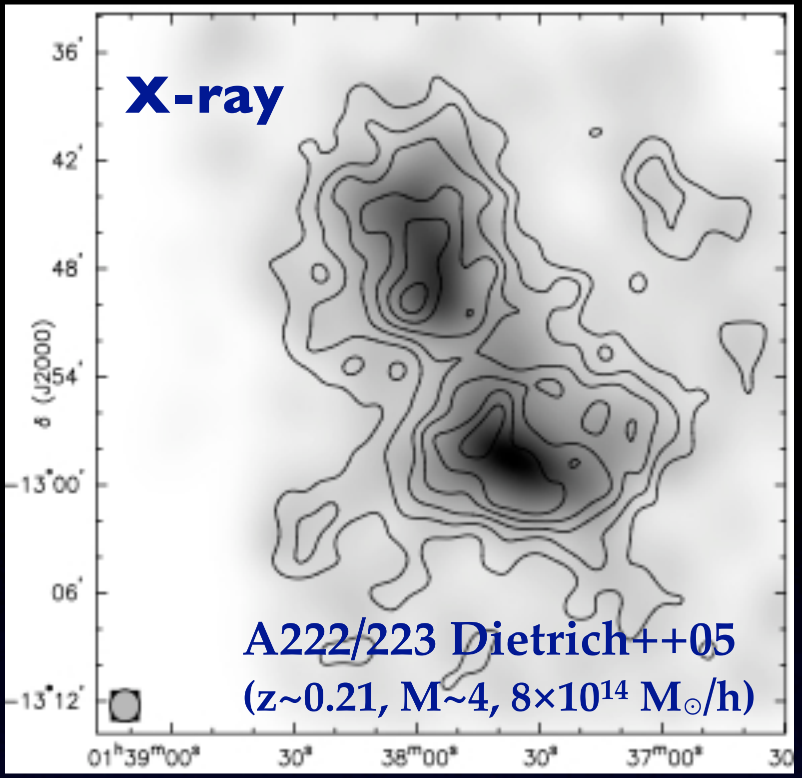
White, Hernquist, & Springel 02

Questions about Filaments around Galaxy Clusters

- What are the properties of filaments which surround clusters?
  Extending the work of Colberg, Krughoff & Connolly 05, Aragon-calvo, Shandarin, & Szalay 10

- How do filaments affect cluster observations?

What are Filaments?
(No Unique DEFN)



- Observations
  - Extended warm hot gas between clusters (T ~ 10^5 -10^7 K, 40% of total baryon)
  - Overdensities of galaxies, Orientations of galaxies, etc
- Filament finders
  - Halo based: e.g. Minimal spanning trees (e.g. Barrow++85)
  - Density based: e.g. Hessian of the potential or density (e.g. Hahn++07, Bond++10)

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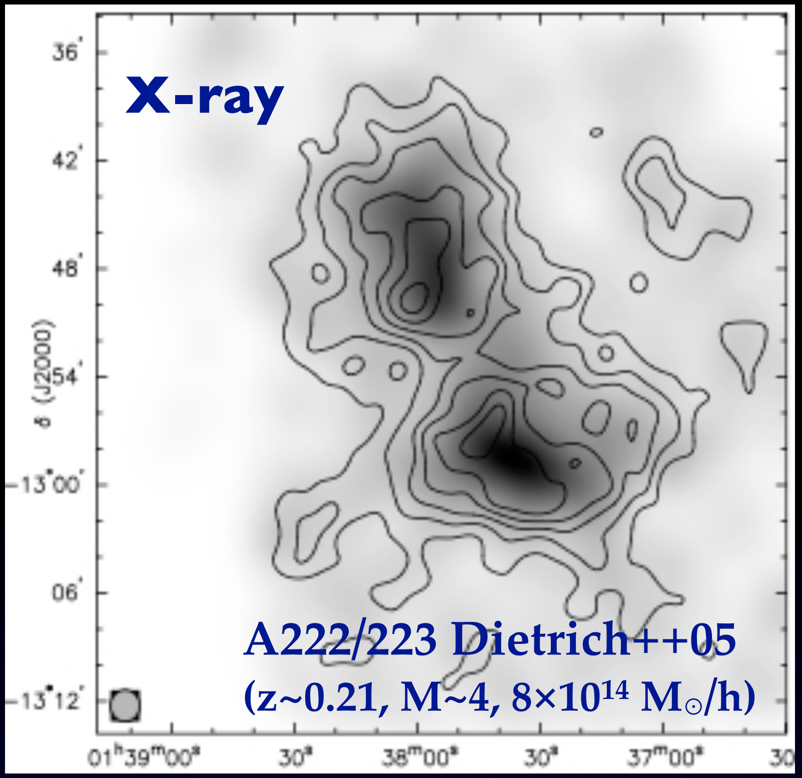

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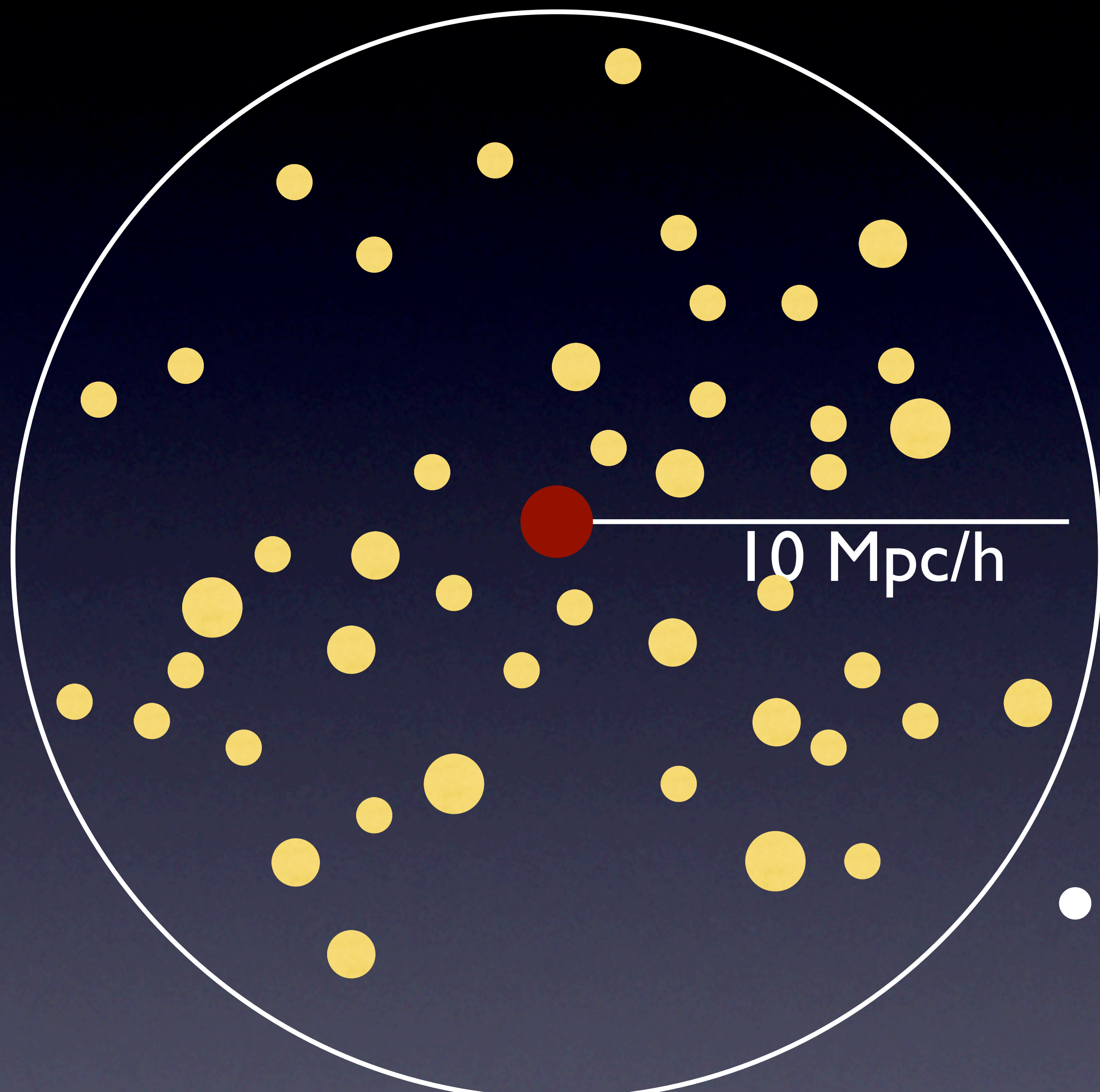
Simulation

- N-body simulation (TreePM code, White 2002)
  - 250 Mpc/h box, 2048^3 particles
  - $\Omega_m = 0.274$, $h = 0.72$, $n = 0.95$, $\sigma_8 = 0.8$
  - Halos via FoF with linking length ~0.168
  - Focus here on z=0.1
- Mock observations
  - Based on dark matter and subhalo distribution

Our Method



- Based on halos (Zhang et al. 2009) (min. halo mass: 3×10^{10} $M_\odot$)
  - Take each massive halo
  - Look at neighbors (<10Mpc/h)
  - See which bridge is densest in terms of halos ($>5\rho_b$)
  - Cut at the most massive halo in filament (>3Mpc/h)
- Add various refinements
  - Analogous to spherical overdensity of the cluster
  - Merge nearby filaments, etc..

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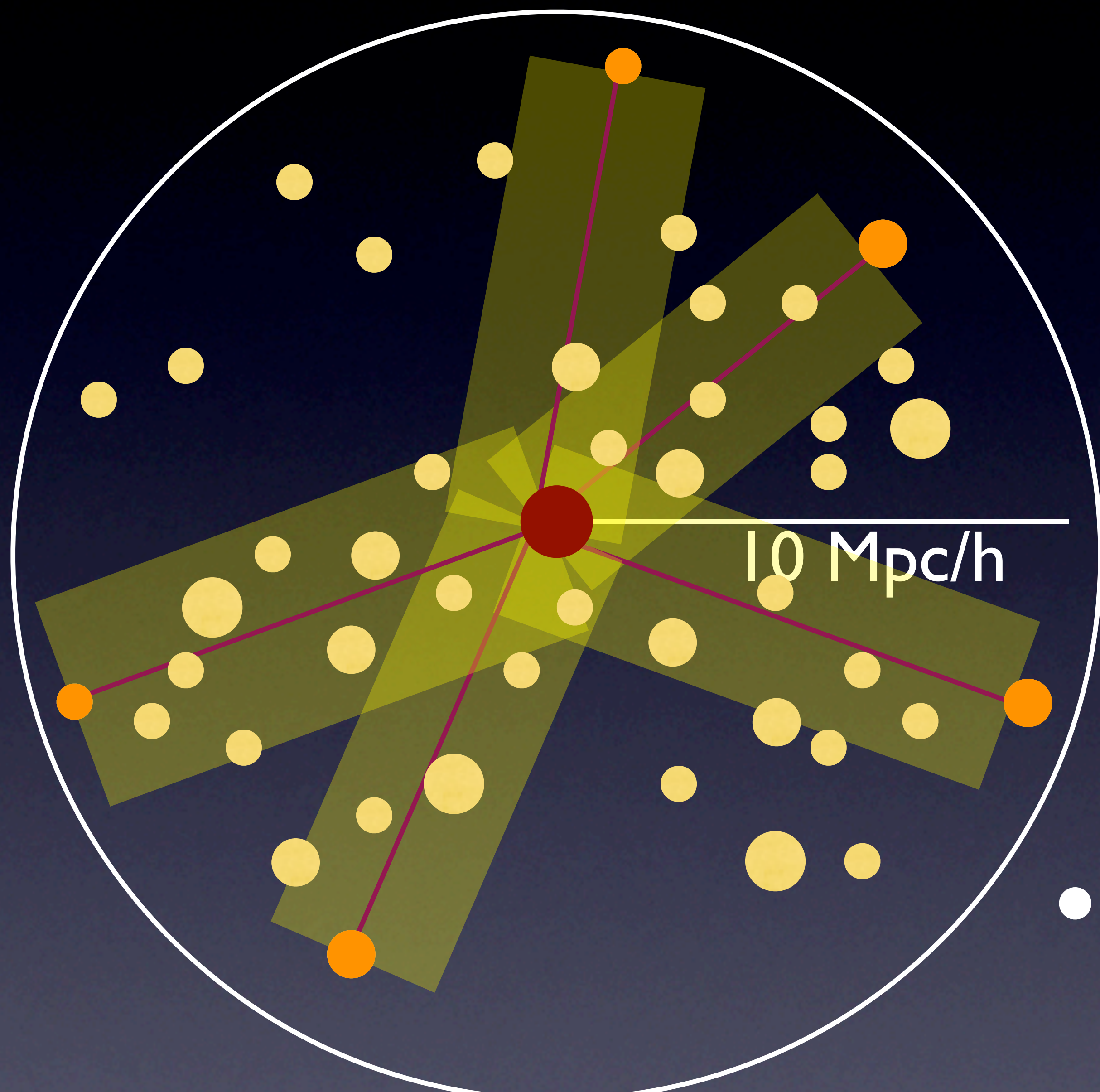

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Noh & Cohn MNRAS (2011)

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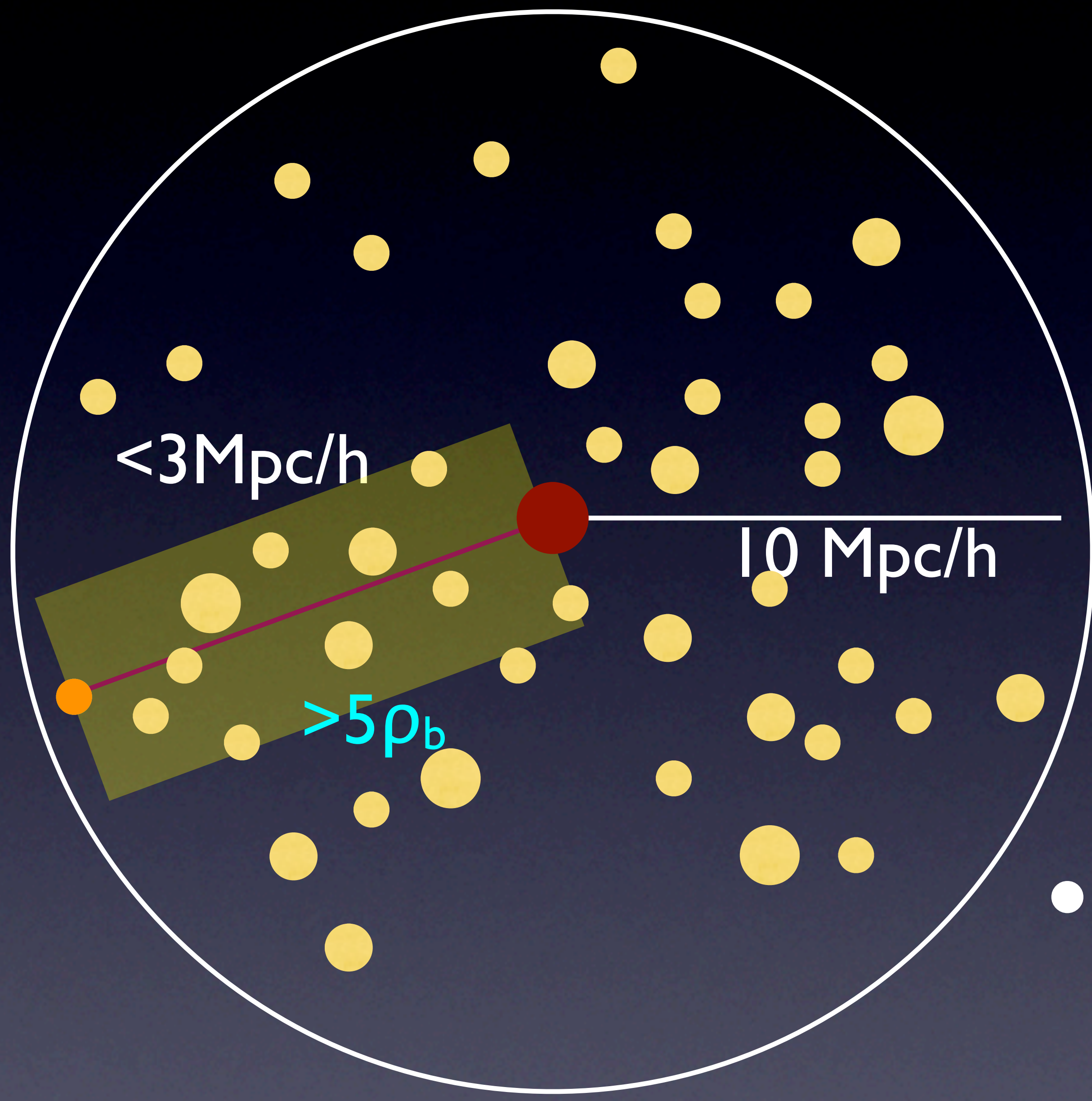

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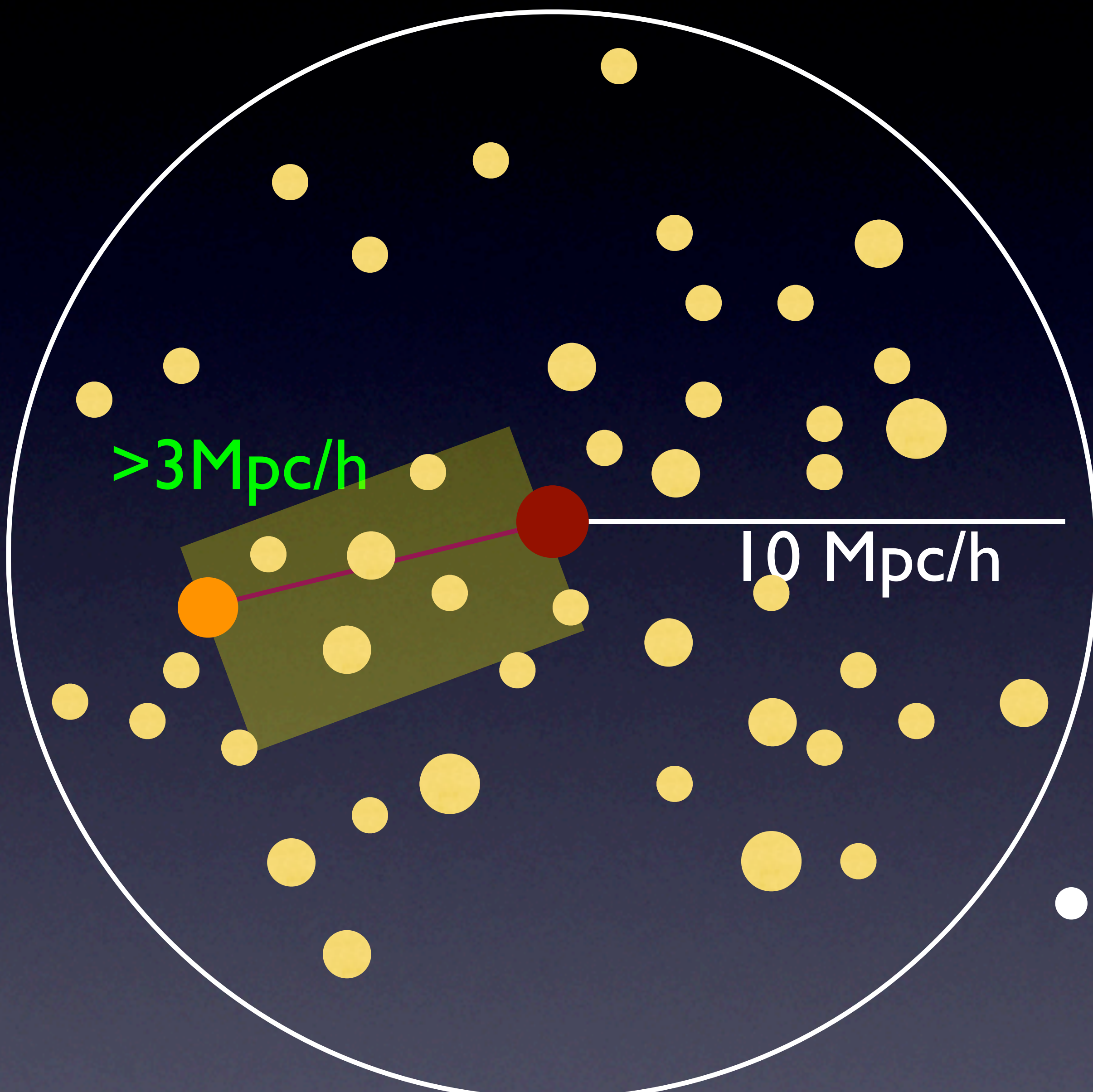

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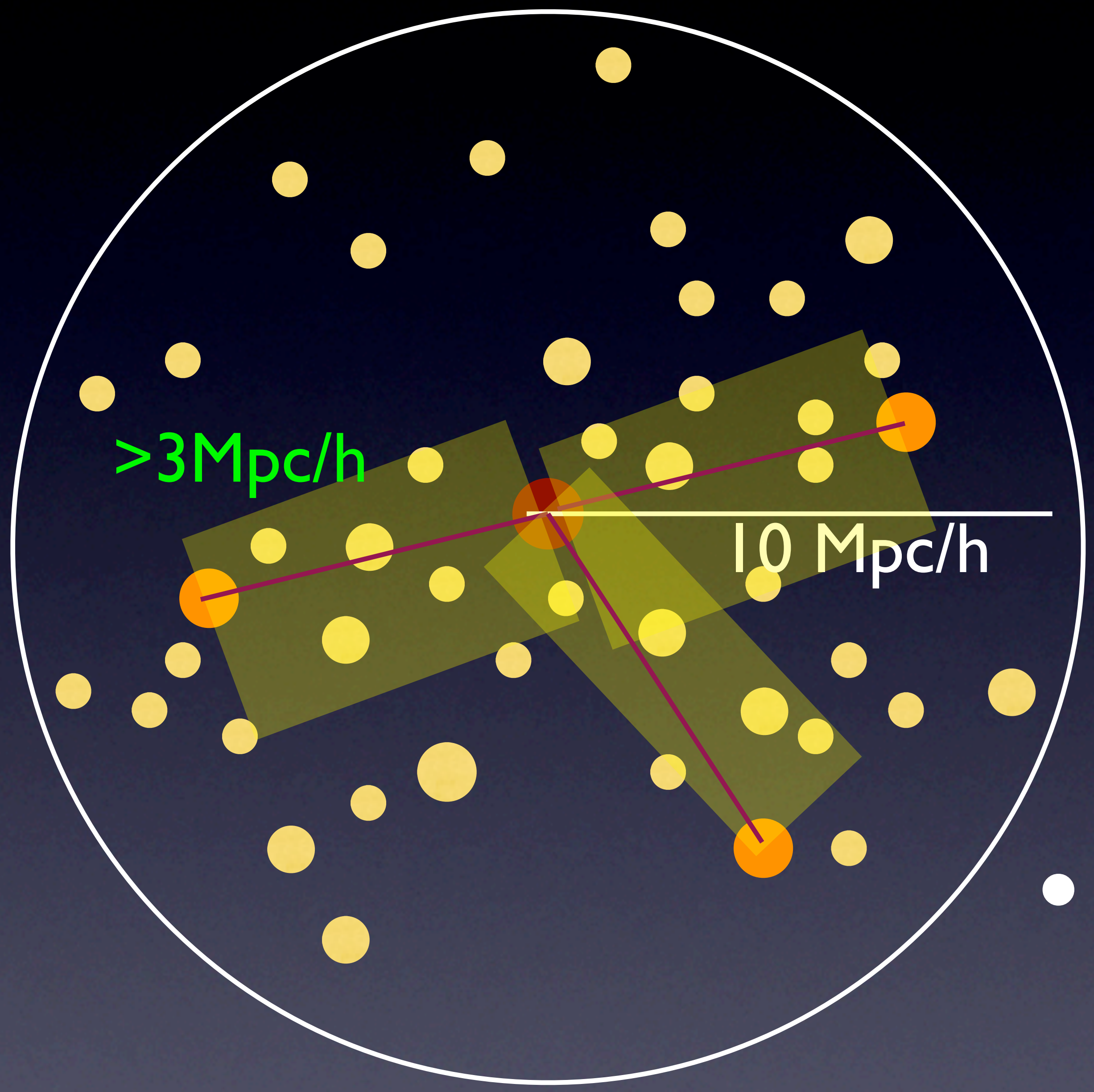

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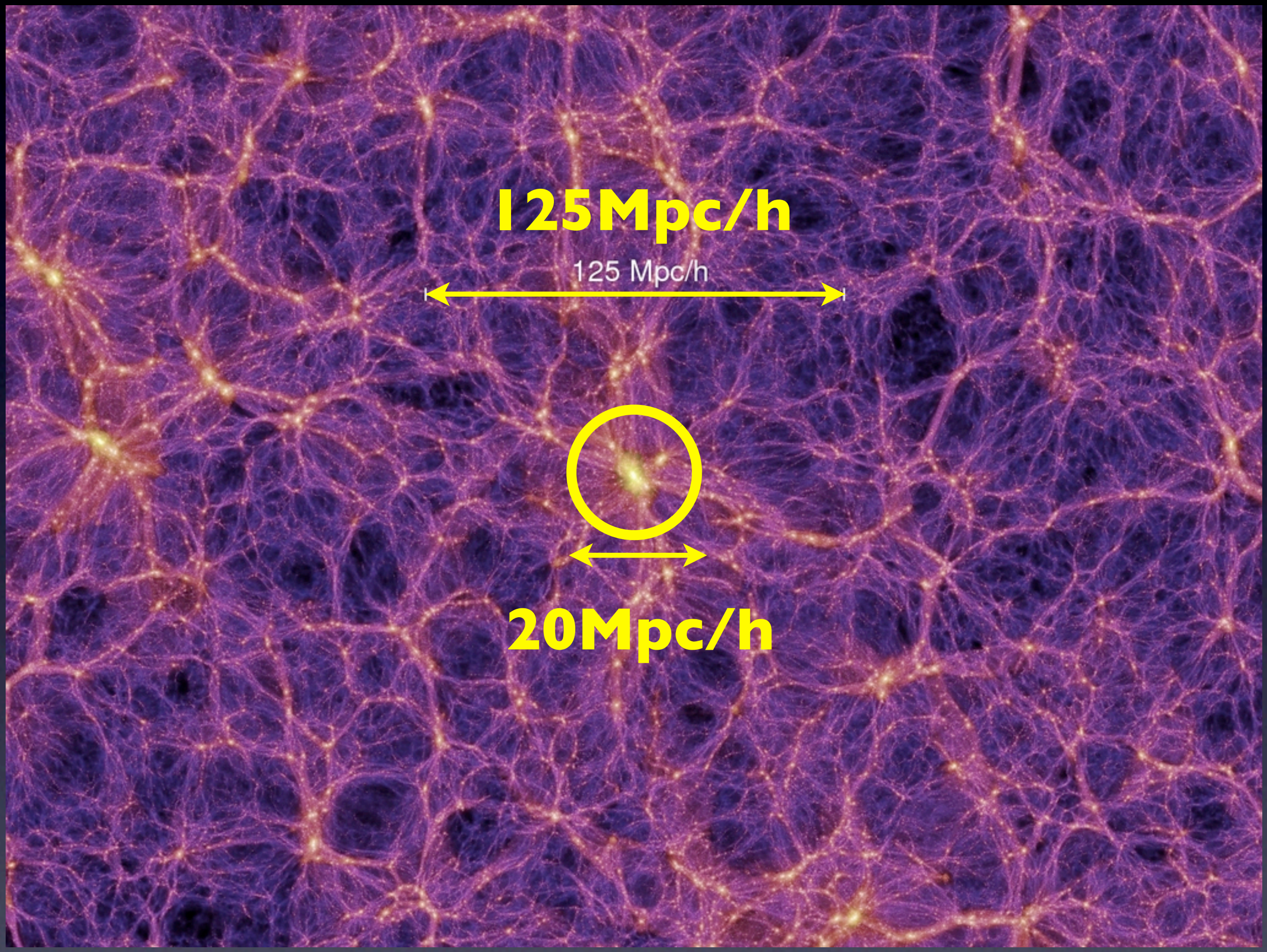
Statistics of Total Filaments (z=0.1)

- Number of filaments in total: ~30000
- Number of nodes: ~44000
- Halo mass fraction in filaments: ~45%
- Halo number fraction in filaments: ~36%

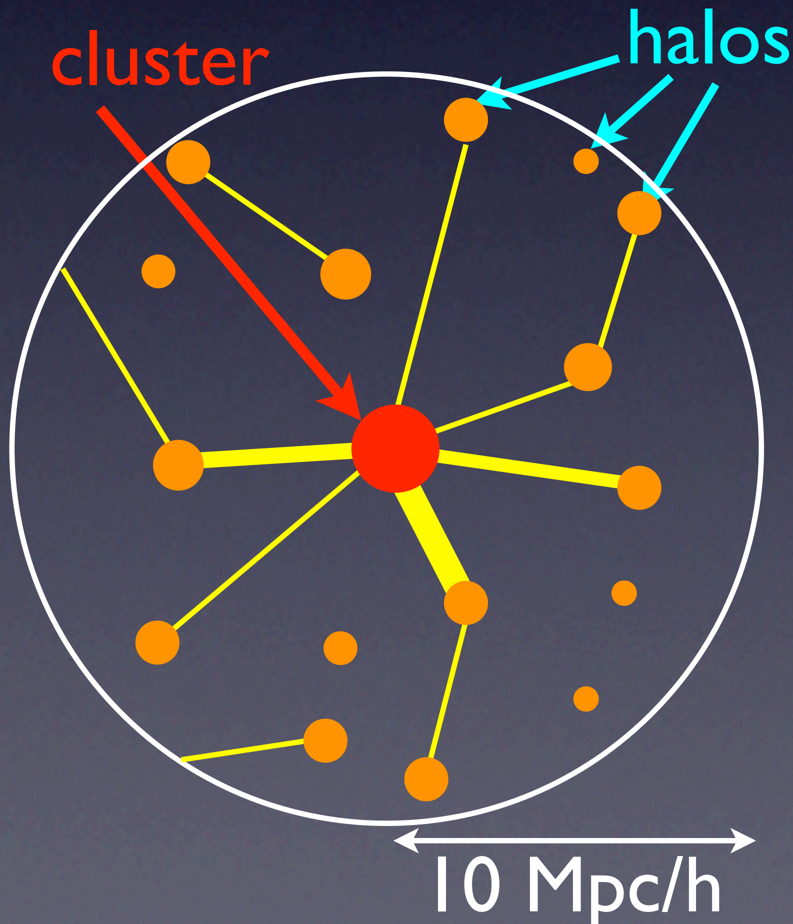
Filaments Surrounding Clusters

- Finder restricts to local filamentary environment of the cluster
  - Filaments may be longer (e.g. Colberg++05, Gonzalez&Padilla10)

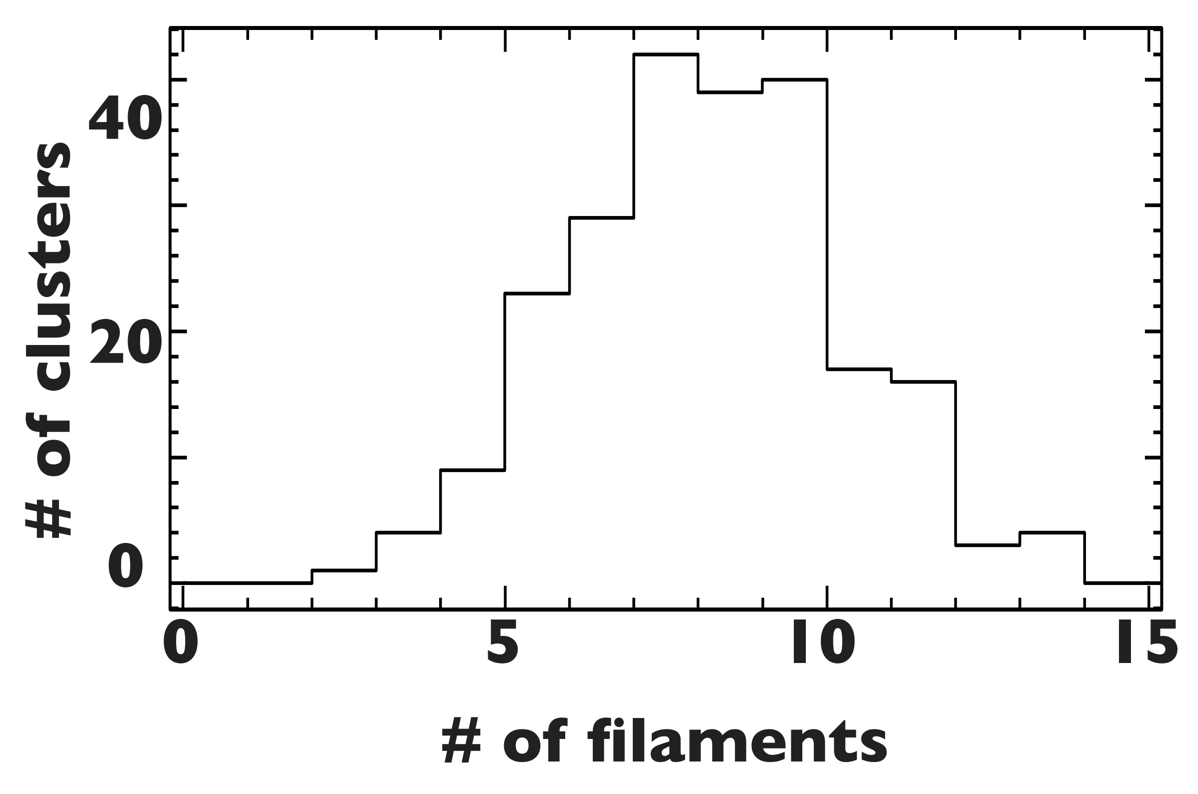


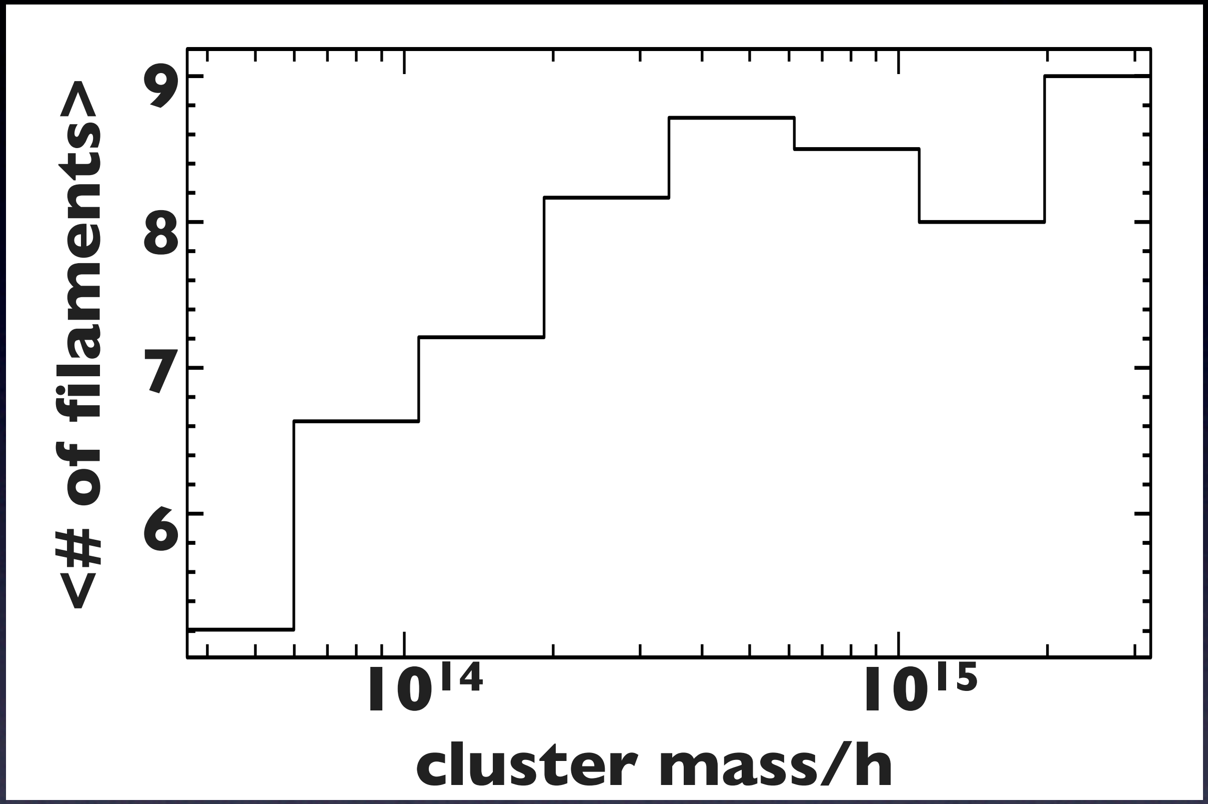
Filaments Surrounding Clusters

- 243 Clusters ($M_{halo} \geq 10^{14}\ M_{\odot}/h$) → 227 nodes
- 10 Mpc/h radius sphere around each cluster
  - ~70% halo mass in cluster filaments



Statistics of Cluster-Filaments



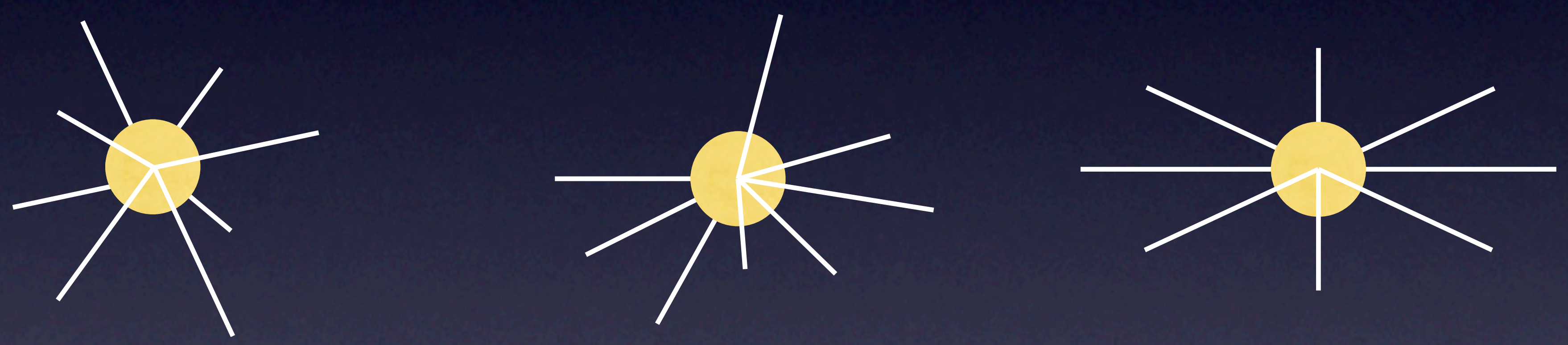


- Typical number of cluster-filaments: ~7-9
  - ~75% of cluster filament mass in the three most massive filaments
- As cluster mass increases, number of cluster-filaments increases
  - Trends agree with previous work (e.g. Colberg++05)

Geometry

What possibilities are there for the filaments?

Schematic example for 8 filaments from a cluster



3D Isotropic

3D Anisotropic

2D Isotropic

Etc...

?

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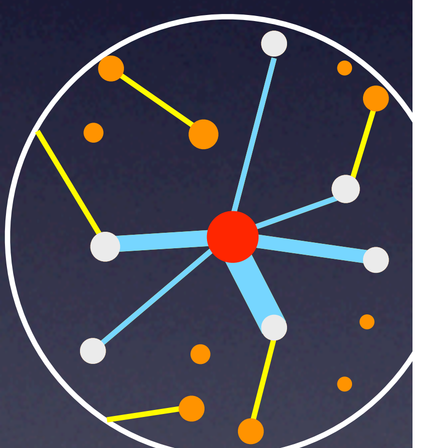
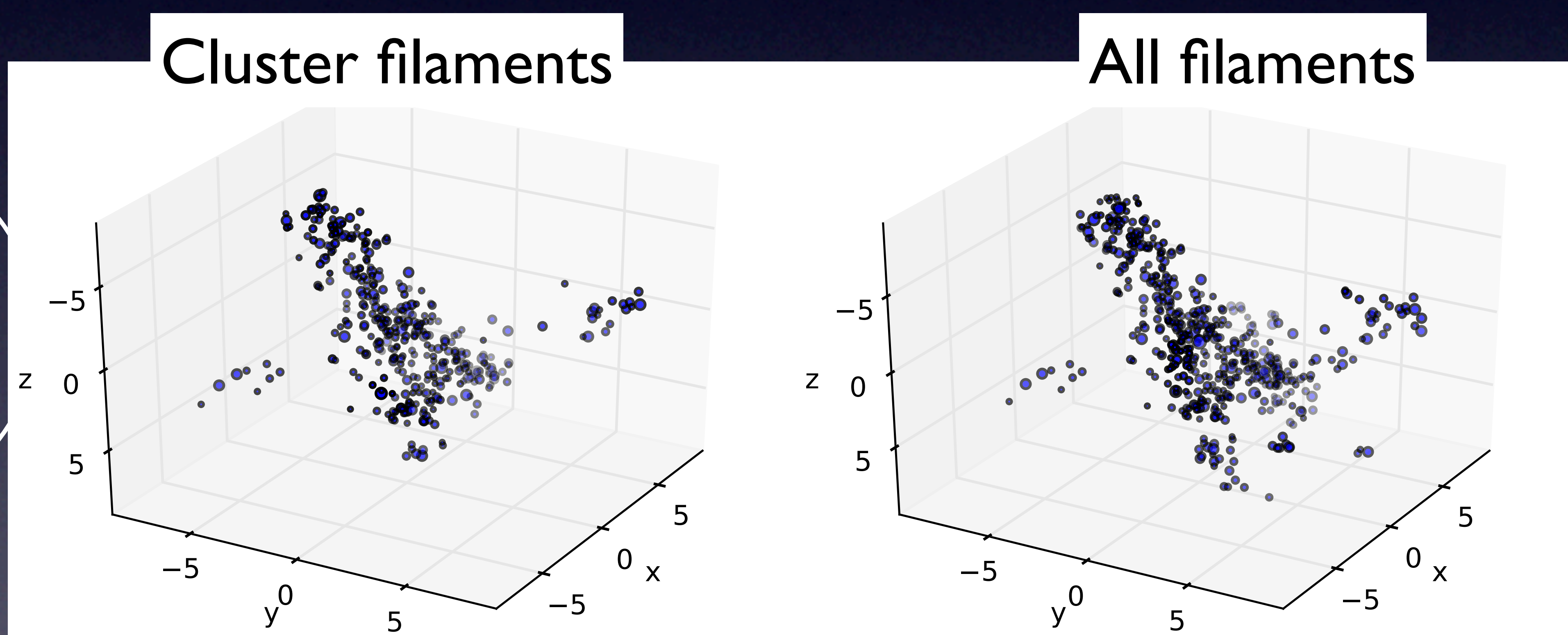
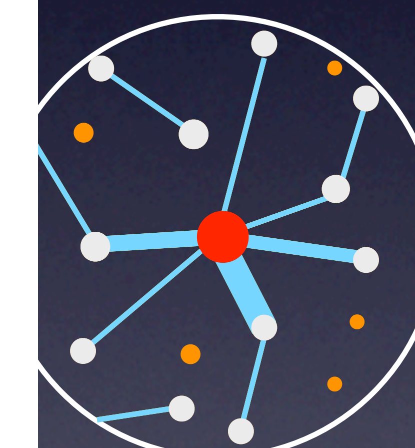
Filament Distribution around Clusters

Example: Filament distribution around one single cluster

$M_{cluster} \approx 2.7 \times 10^{14}\ M_{\odot}/h$

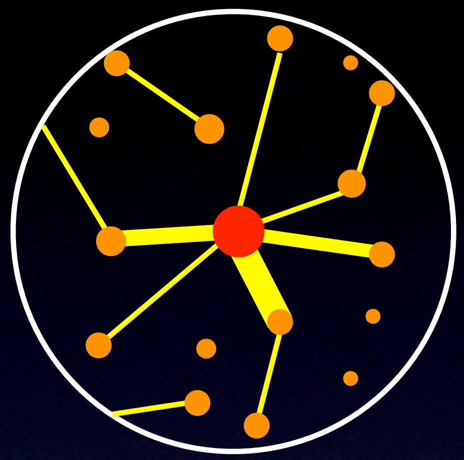




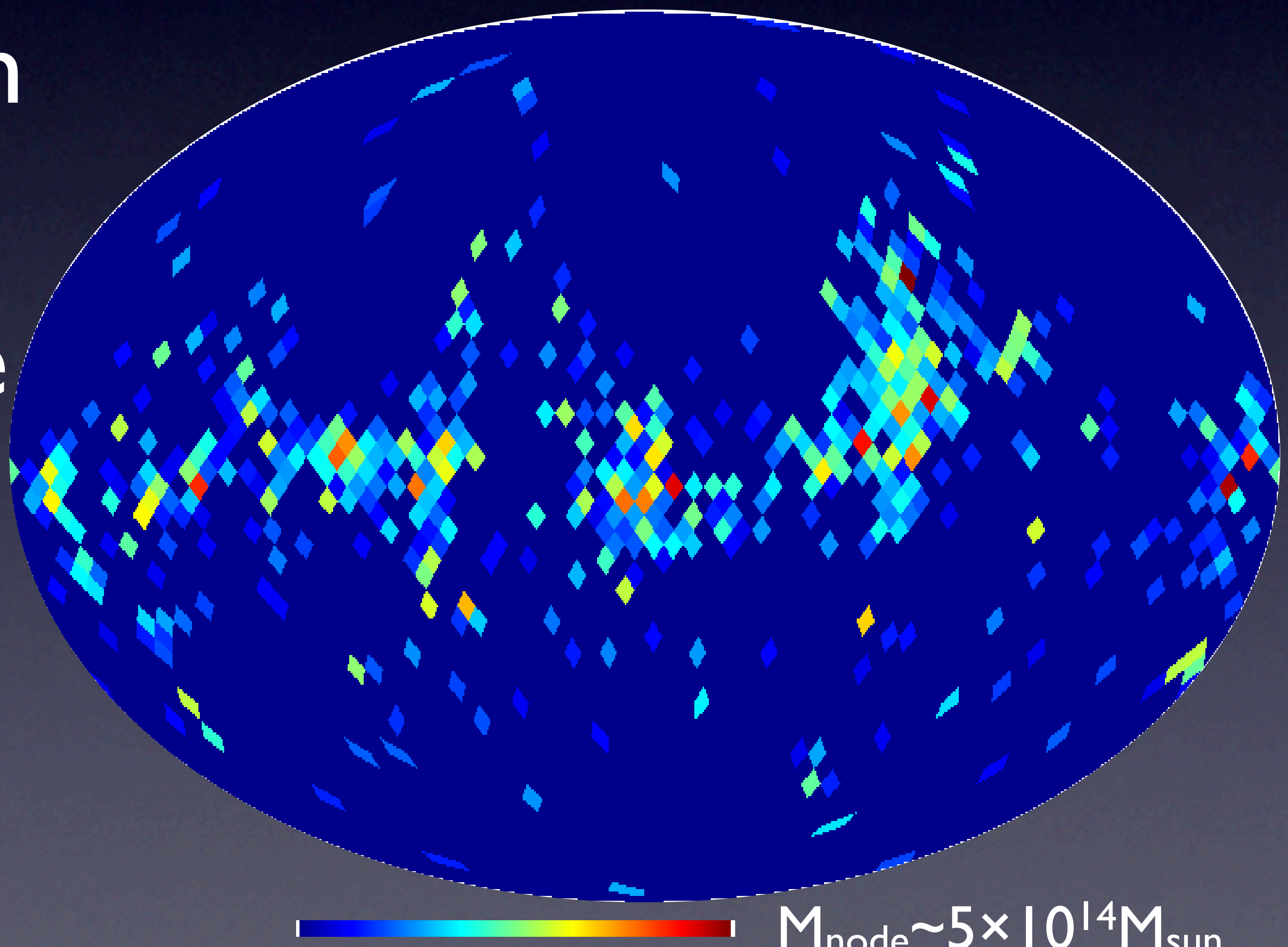


- By eye, filament distribution tends to be planar

Solid Angle Subtended by Filaments



- Project all the halos in all the filaments in 10Mpc/h sphere
- Calculate the solid angle subtended by those halos in filaments
  - About 10-30% of the sky is covered



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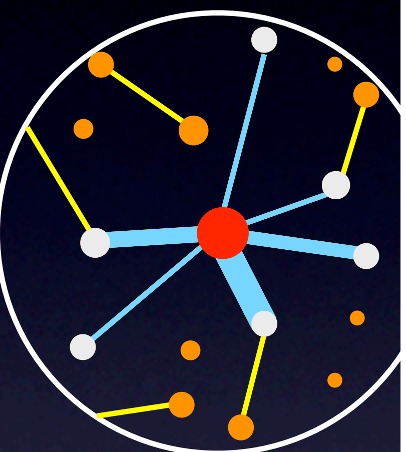
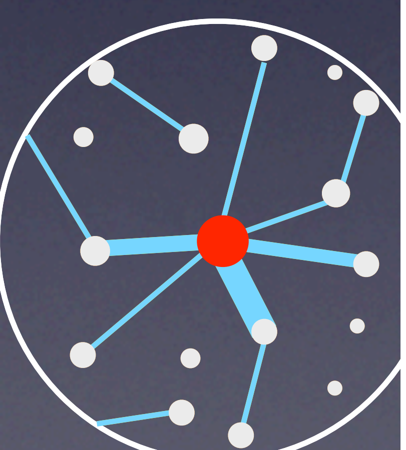
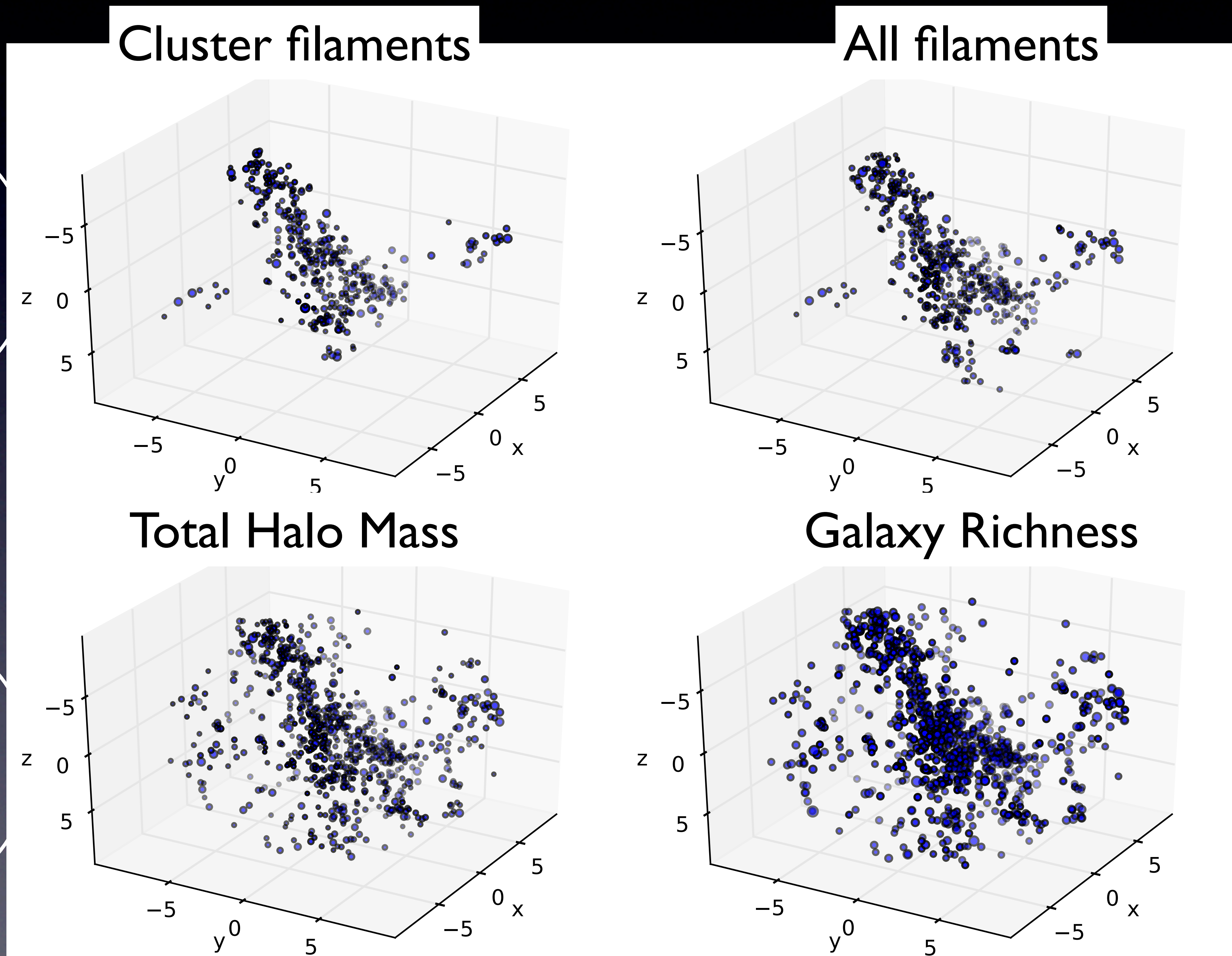
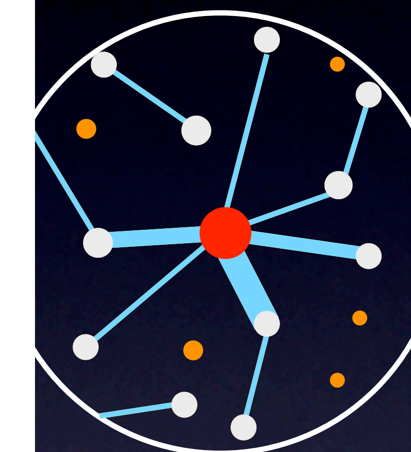
Spatial Distribution around Clusters

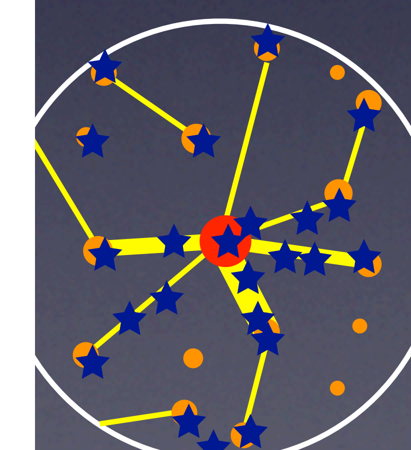
$M_{cluster} \approx 2.7 \times 10^{14}\ M_{\odot}/h$











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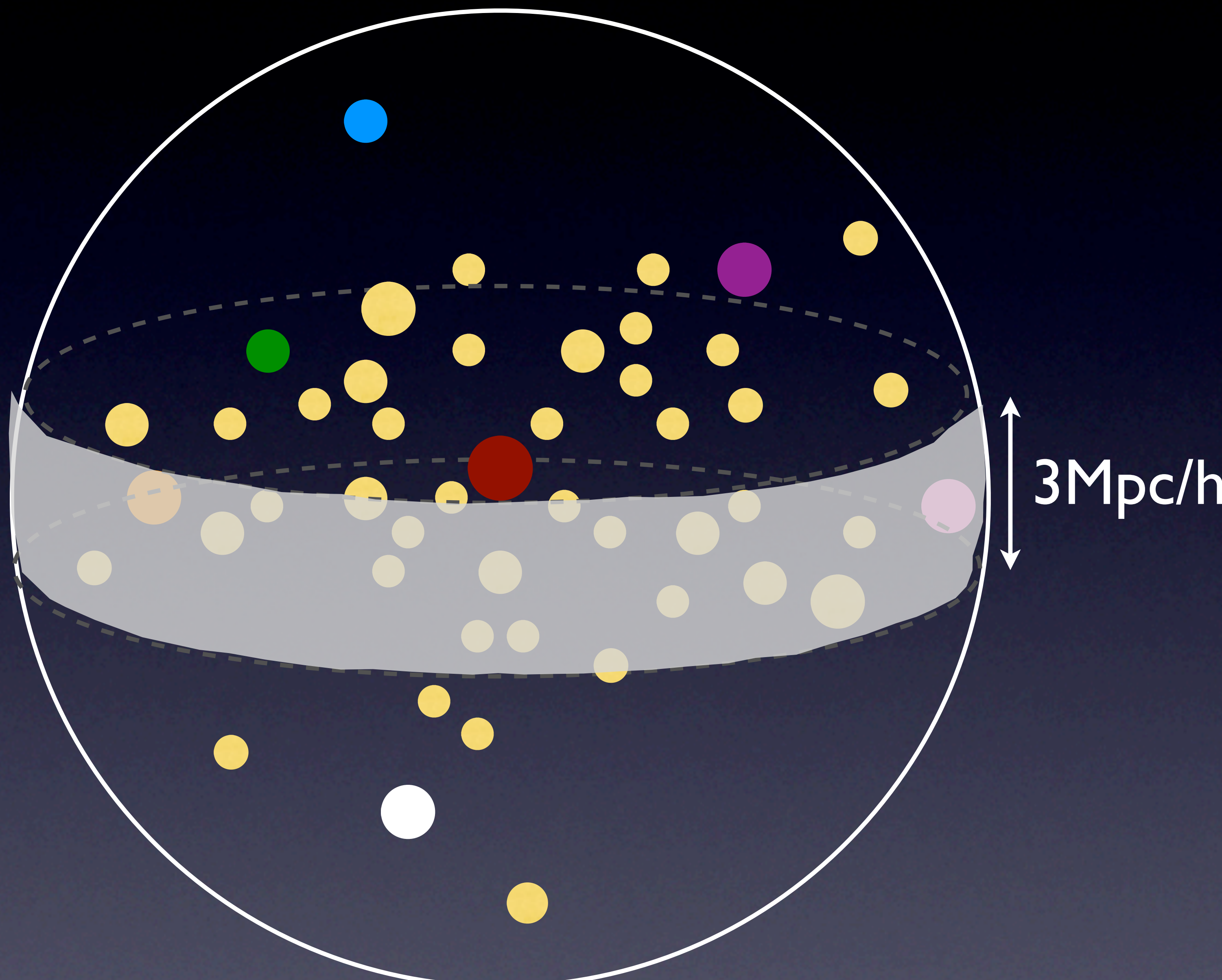
Defining Planes

- "Plane":
  - Disk with 10 Mpc/h radius, 3 Mpc/h thick
  - Orientation: Contain max. mass
    - Cluster-Filaments : Pairs of filaments
    - Other tracers : Random directions



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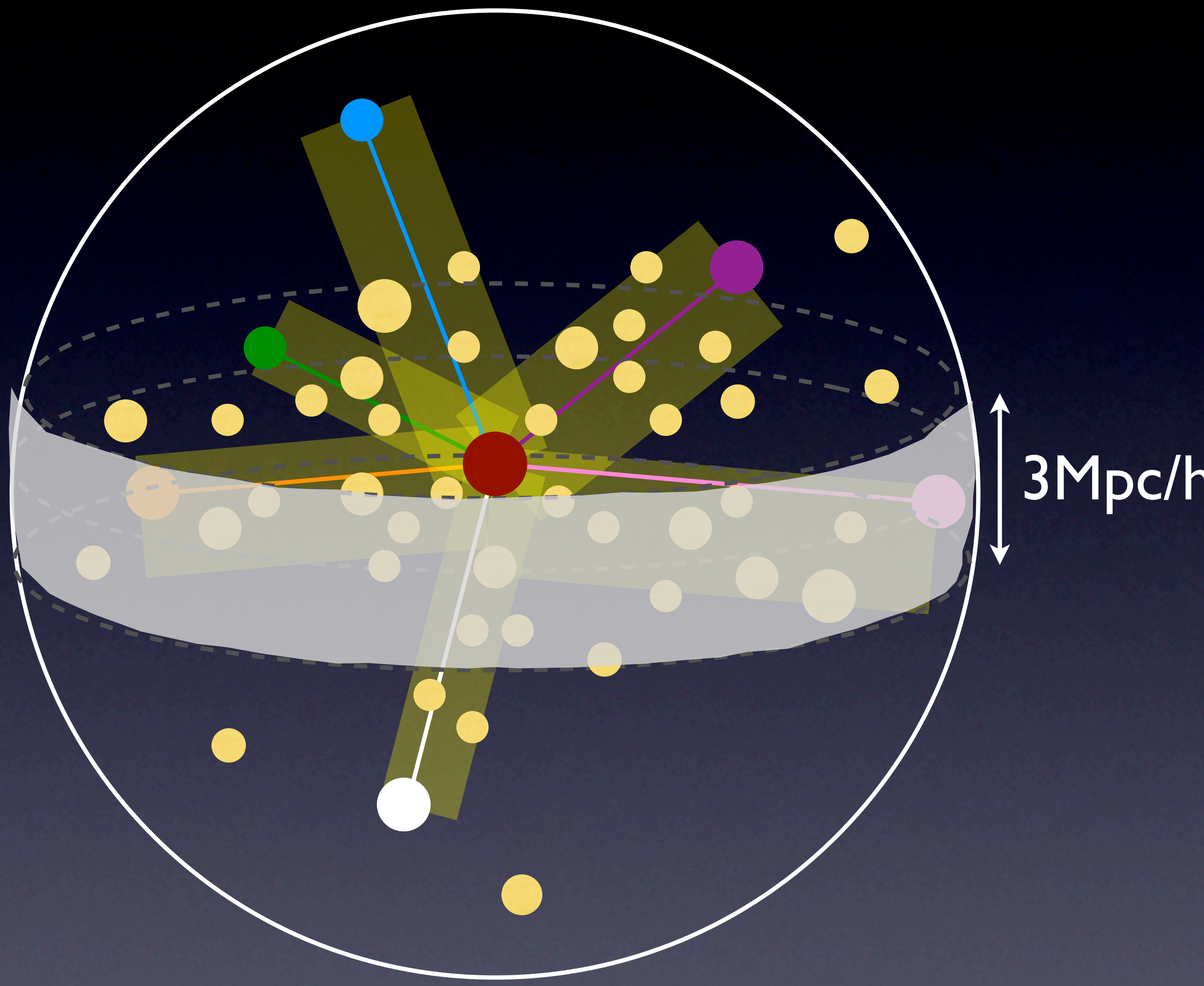

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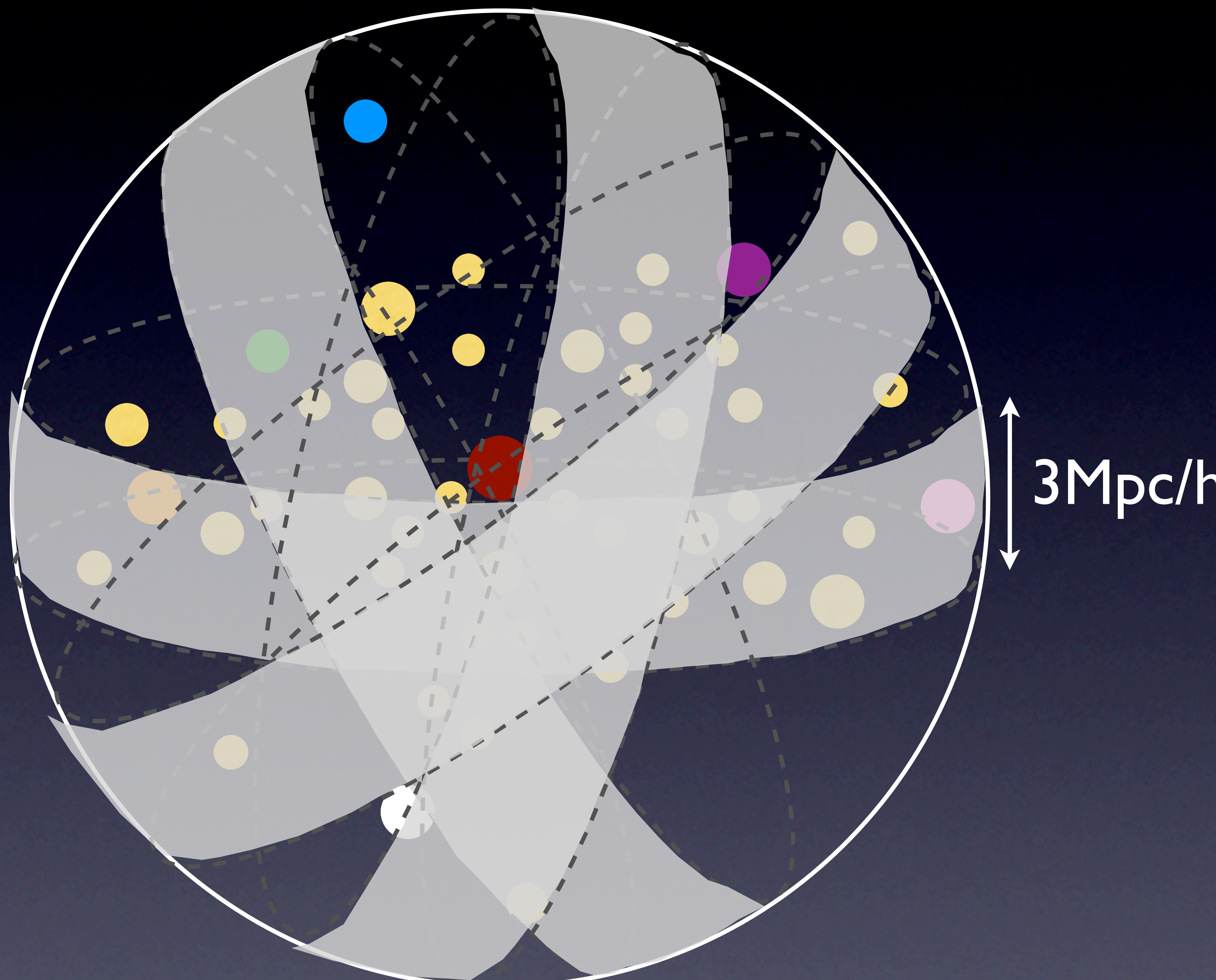
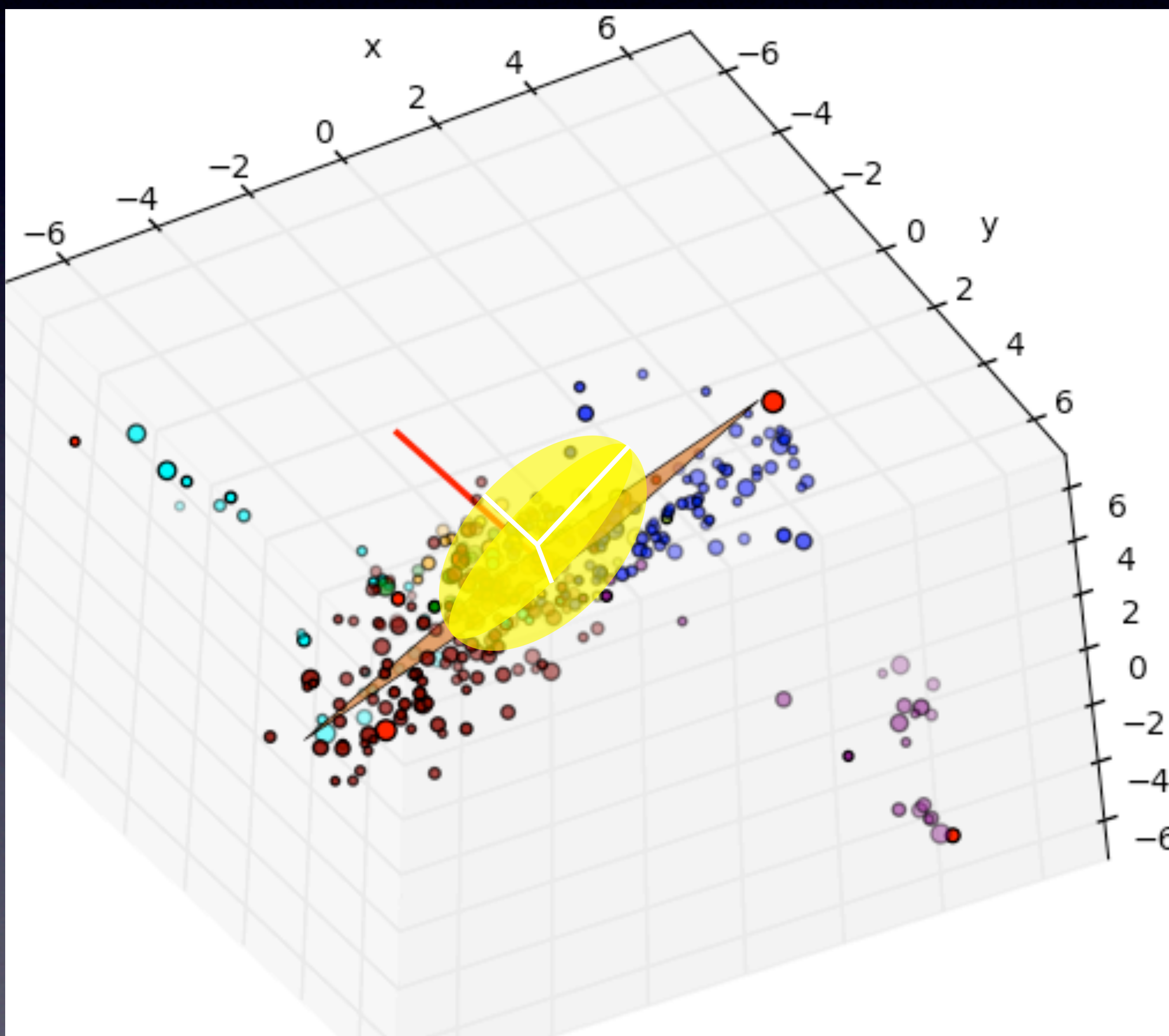


Planar Geometry around Clusters



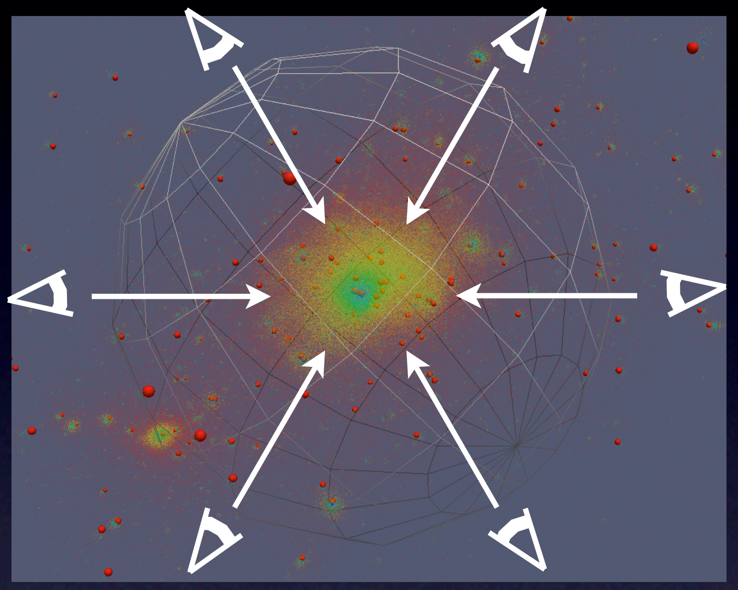
- ~60-80% of mass or richness in “planes”
- Planes from different tracers tend to be aligned
  - Cluster major axis tends to lie in plane
- Normal to the plane is a special direction

Cluster Observables with Planar Environment

Are there correlations between the direction of the plane and the scatter in cluster mass measurements?

Mass measurements in simulation

For more detail, see White, Cohn, & Smit 10



- Mass along 96 different lines of sight
- Mass measurements via
  - Richness
    - N_{red}: Red galaxies, Max BCG, colors using Skibba & Sheth 09
    - N_{phase}: All galaxies, cluster membership using Yang, Mo, & van den Bosch 08 (phase space)
  - Velocity dispersions ($V_{3\sigma}$, V_{phase}): dynamics of galaxies
  - SZ flux: based on the mass of halos, cylinder, r_{180b}
  - Weak lensing: SIS or NFW profile, cylinder, r_{180b}

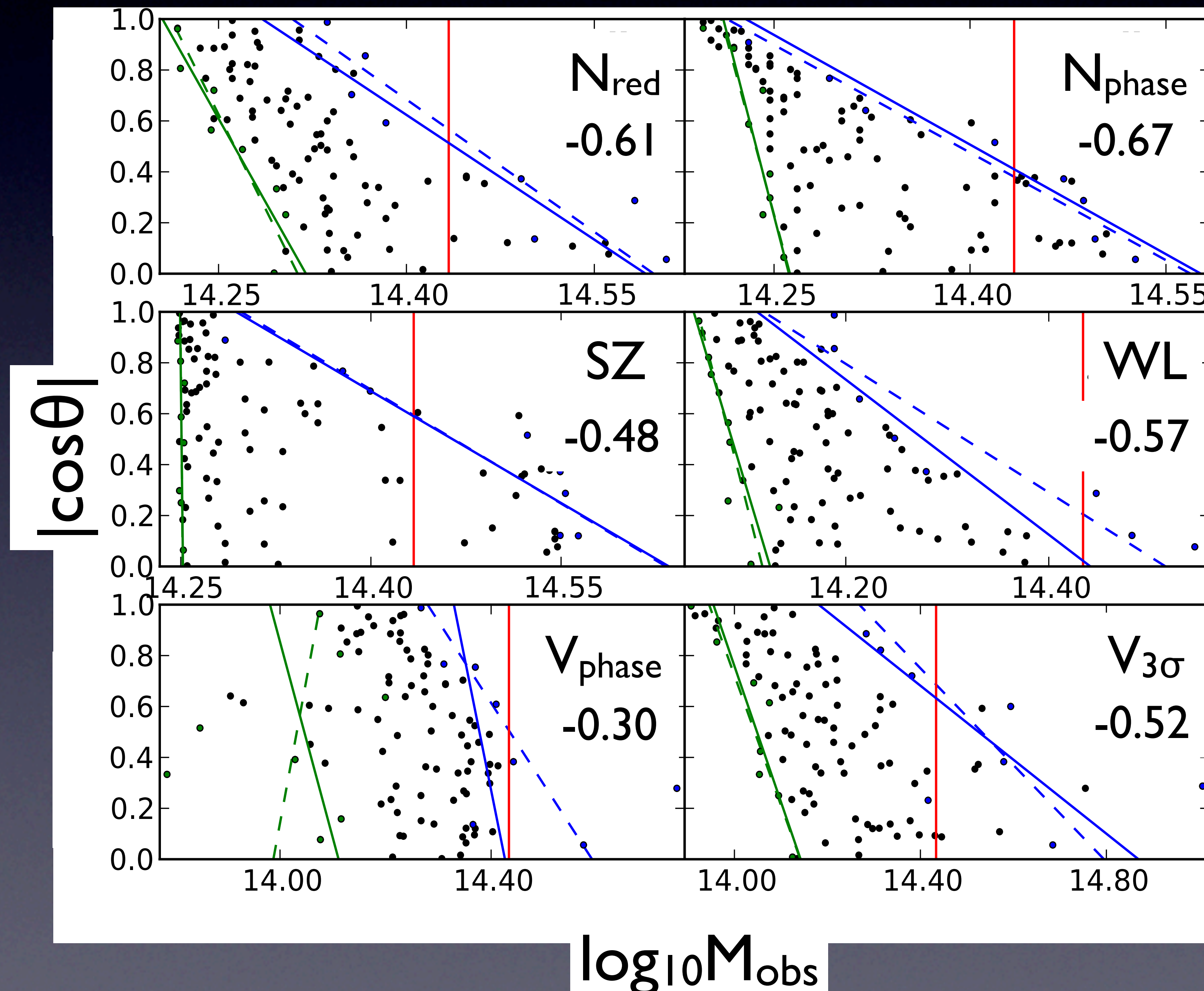
Planar Environment vs. Observables

- Consider the angle of normal to plane with the line of sight for cluster observation

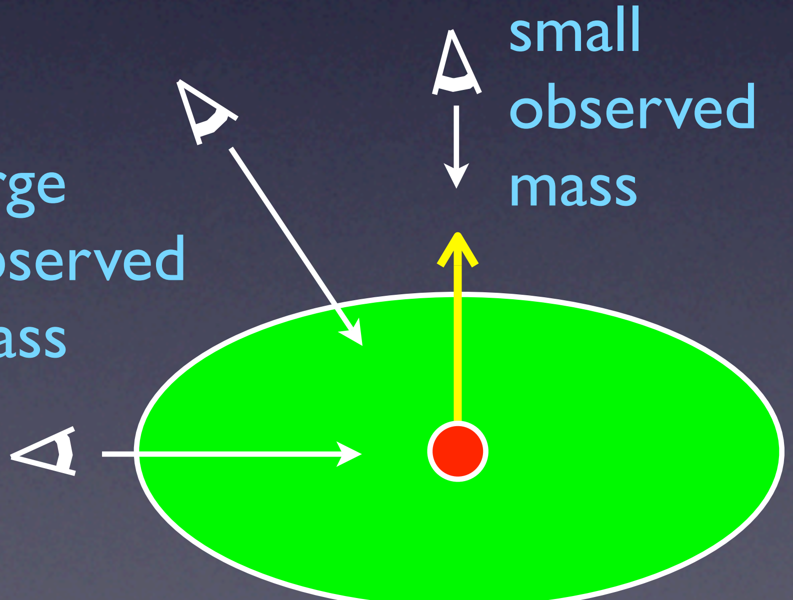
Noh & Cohn MNRAS (2011)

Example of correlation around one cluster

$M_{cluster}$=2.7×10^{14} $M_{\odot}$/h



Correlation between angle with plane and observational scatter



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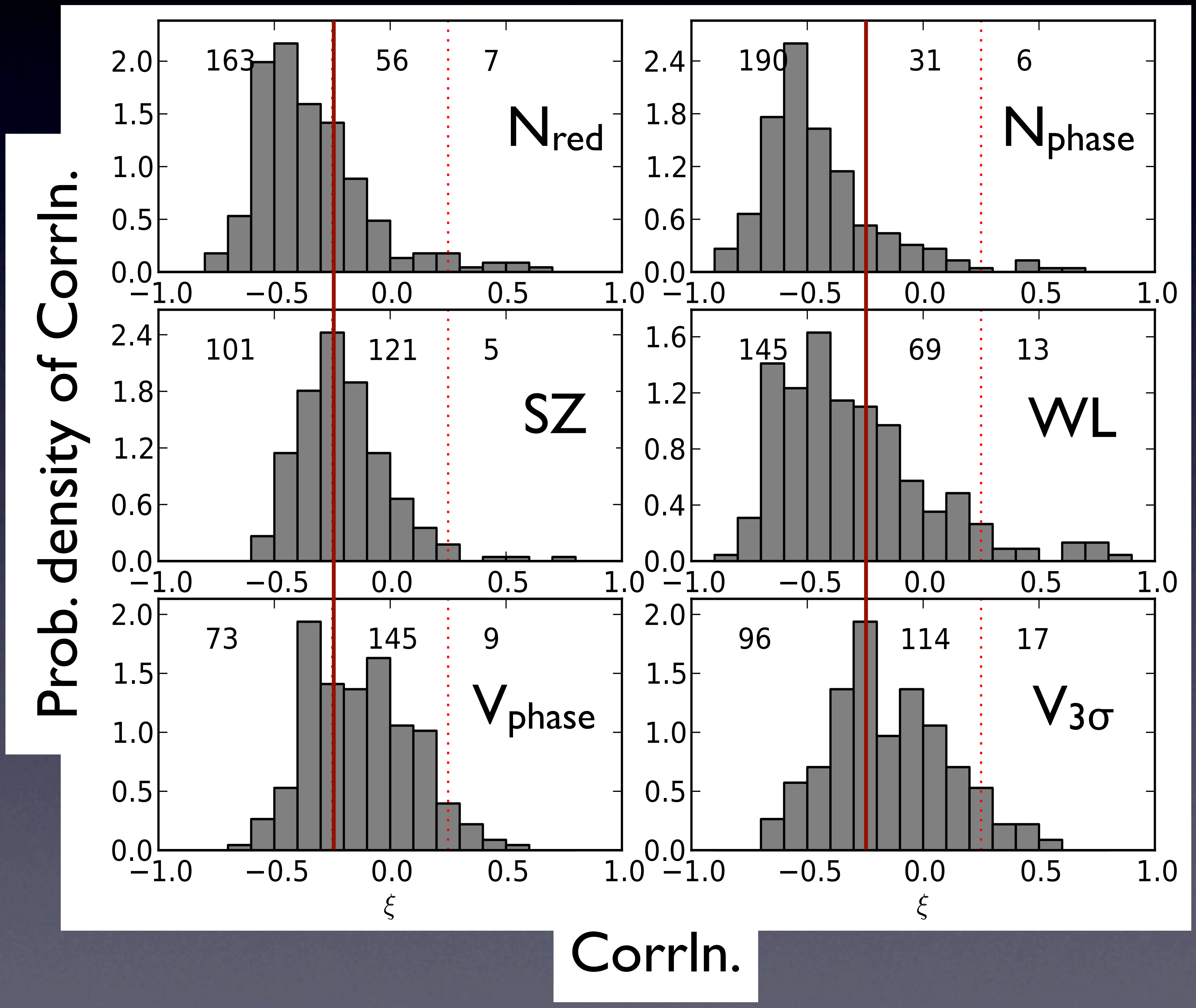
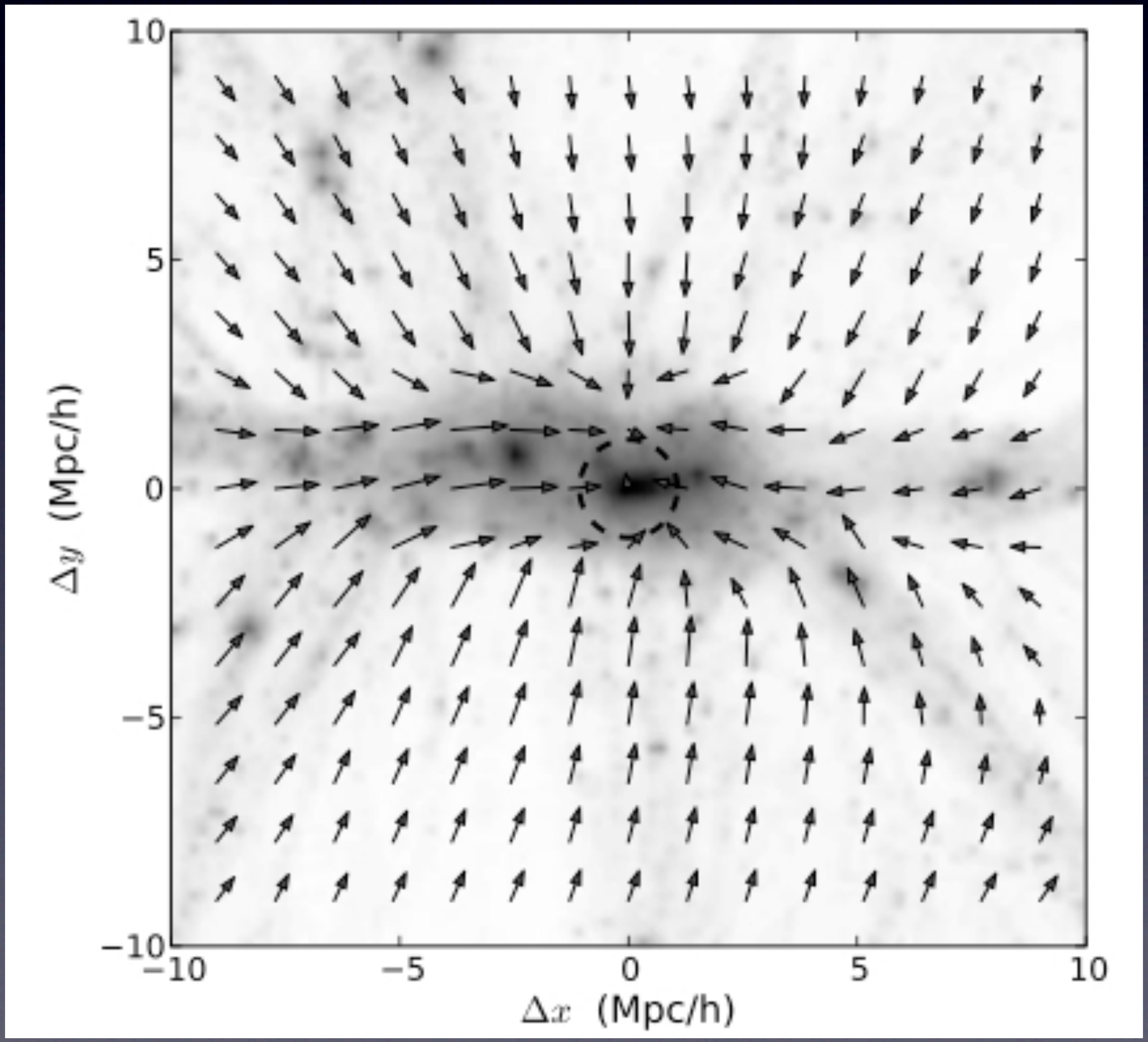
Correlation coefficient distribution for all clusters



- Significant correlation (< -0.25) for many clusters
- Corrln. depends on the type of measurement

Scatter in a given mass measurement is correlated with the filamentary environment (via projection effects)

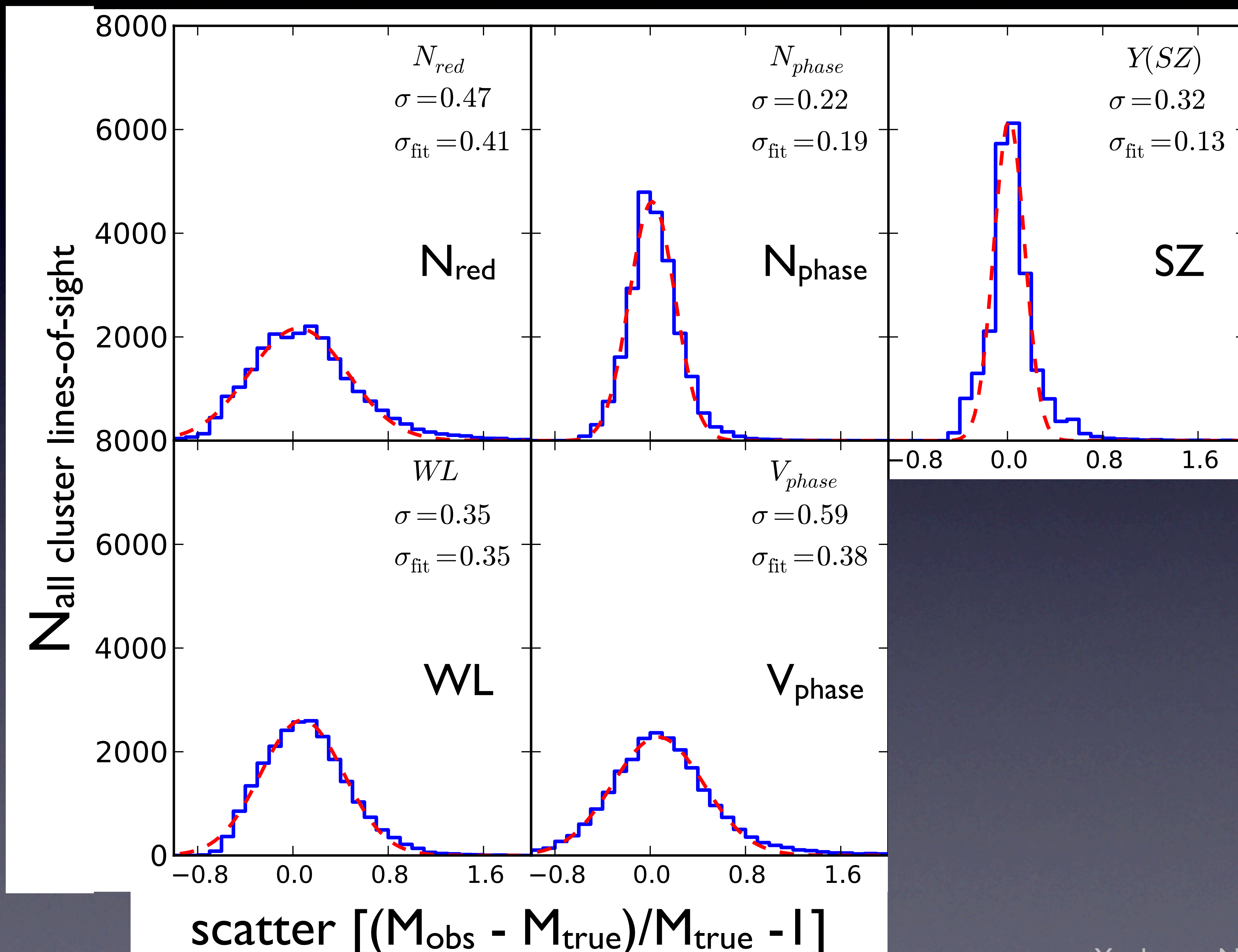


White, Cohn & Smit 11

- Are the scatters in different cluster mass measurements correlated with each other?
- What are physical origins of the scatters of cluster mass measurements?

Noh & Cohn MNRAS (2012)

Scatter in Cluster Mass Measurements



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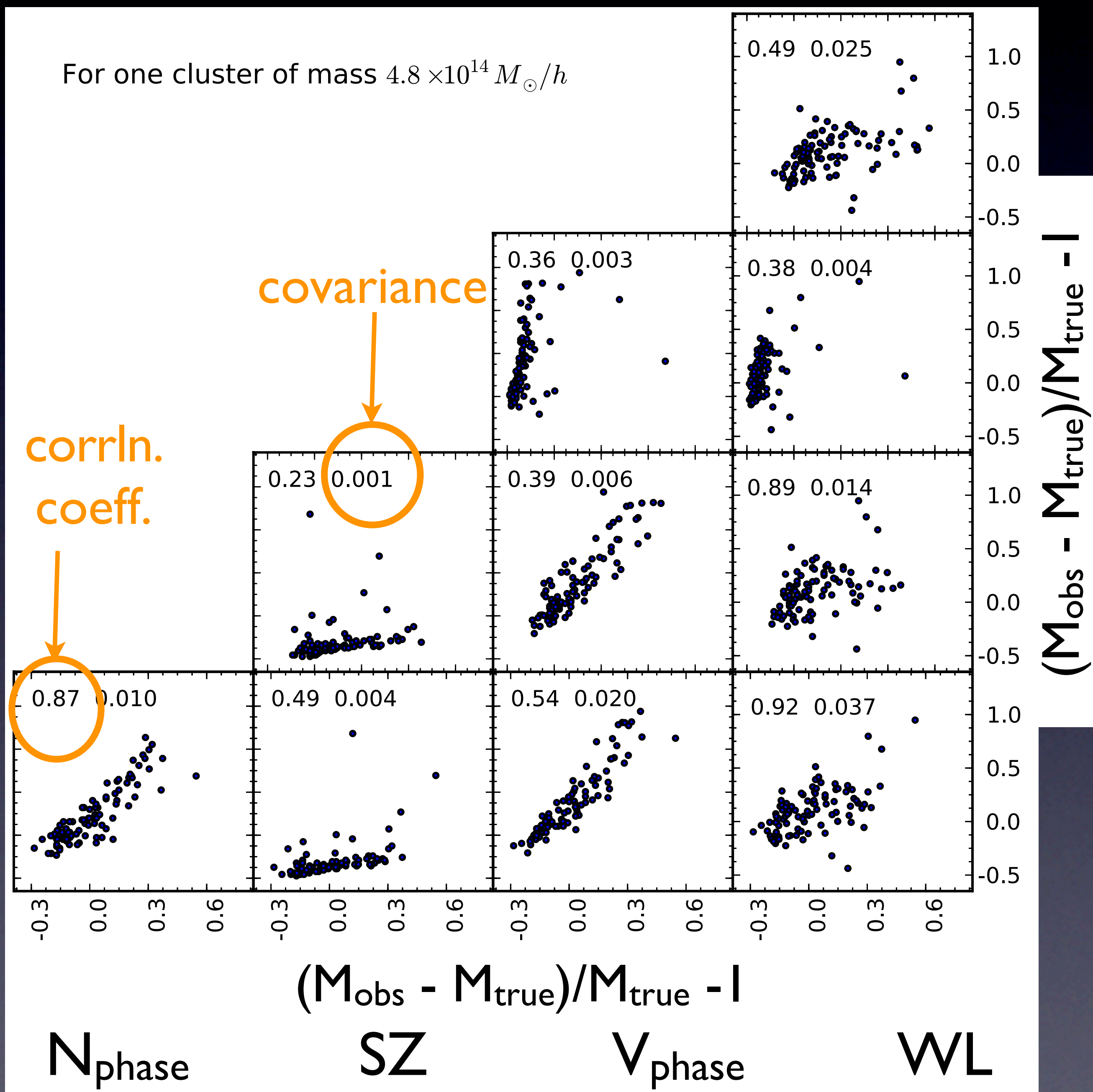
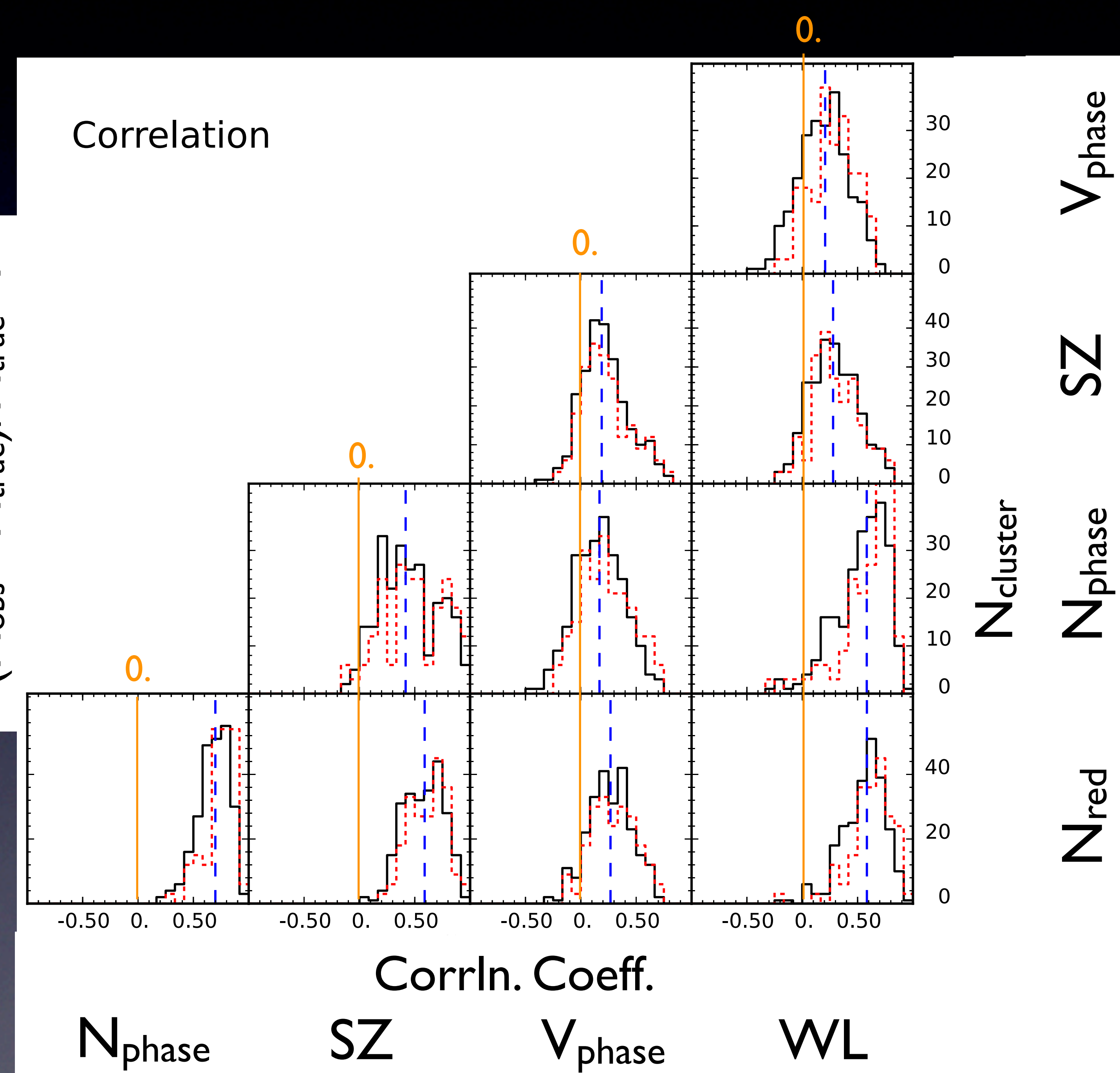
Correlated Scatter



A single cluster



Ensemble of clusters

Correlated Mass Scatter

- Why is this important?

Rykoff++08, Stanek++10, White, Cohn, & Smit10, etc.

  - Stacking of ensemble of clusters can result in a bias
  - Error estimates can be incorrect for the joint measurement of one cluster

Analyses are beginning to include: Rozo ++09, Mantz++10, Benson++11, etc.
A recent application to an observational cluster sample: Angulo++12 etc.

- How can we take care of it?
  - Calibrate with simulations
  - Understand what it is physically related to

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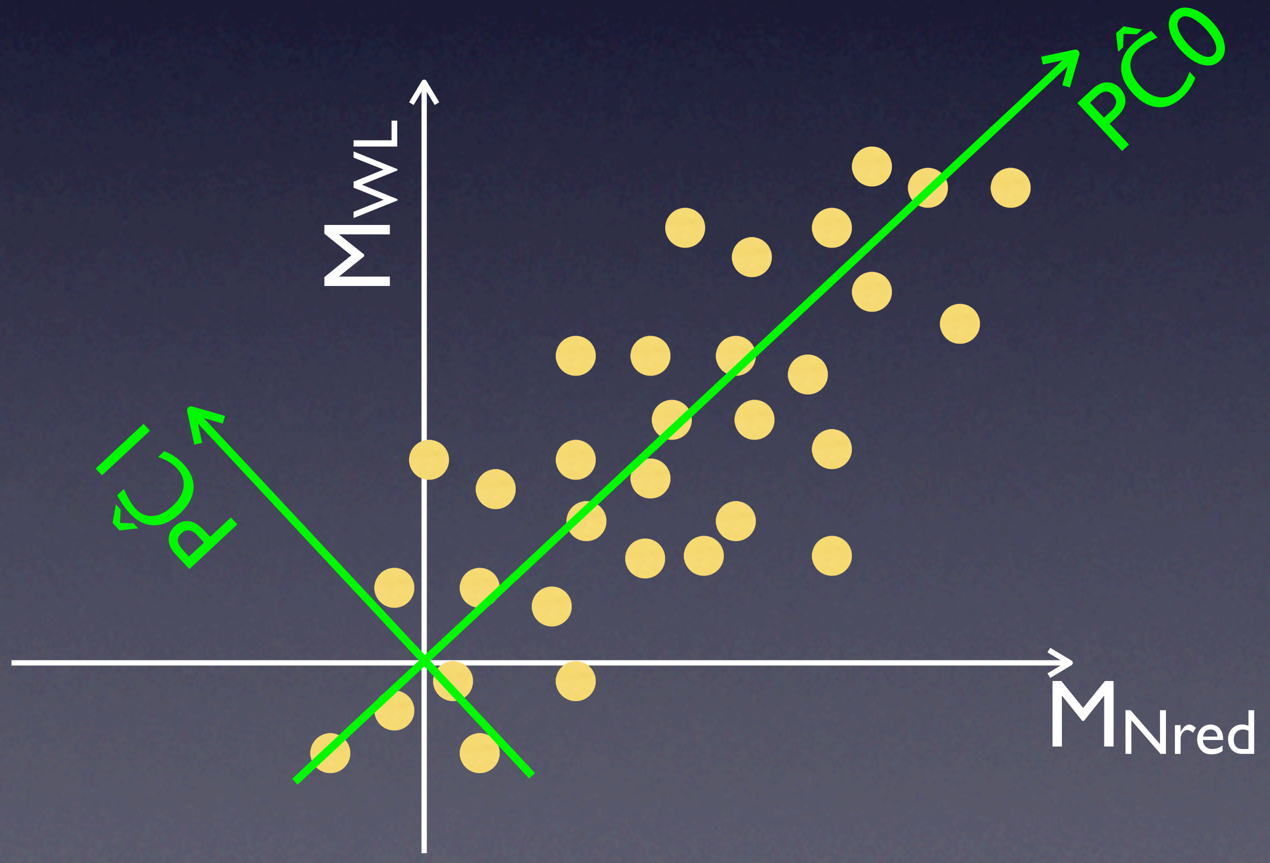
Principal Component Analysis(PCA)

- Convert a set of correlated variables into a set of independent variables



- PĈs are eigenvectors of covariance/correlation matrix
- Corresponding eigenvalues indicate the importance of PĈs
  - PĈ0 gives the direction of the largest variance

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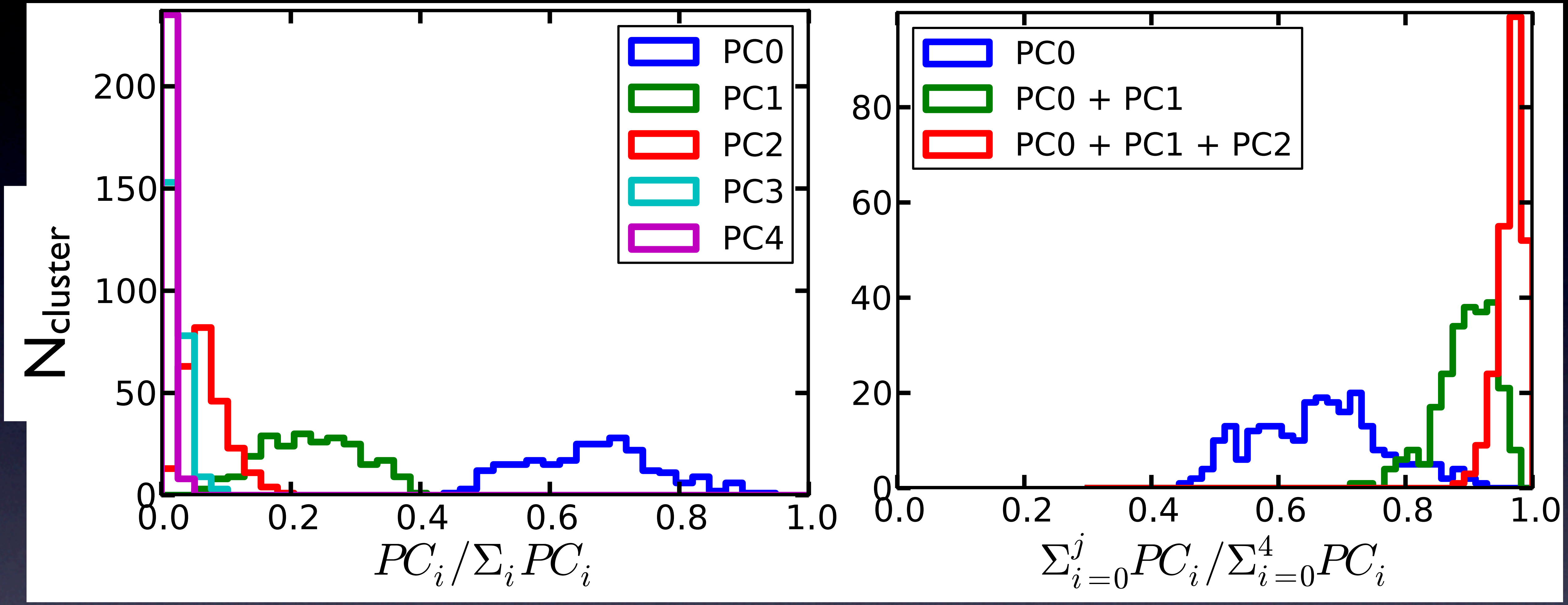
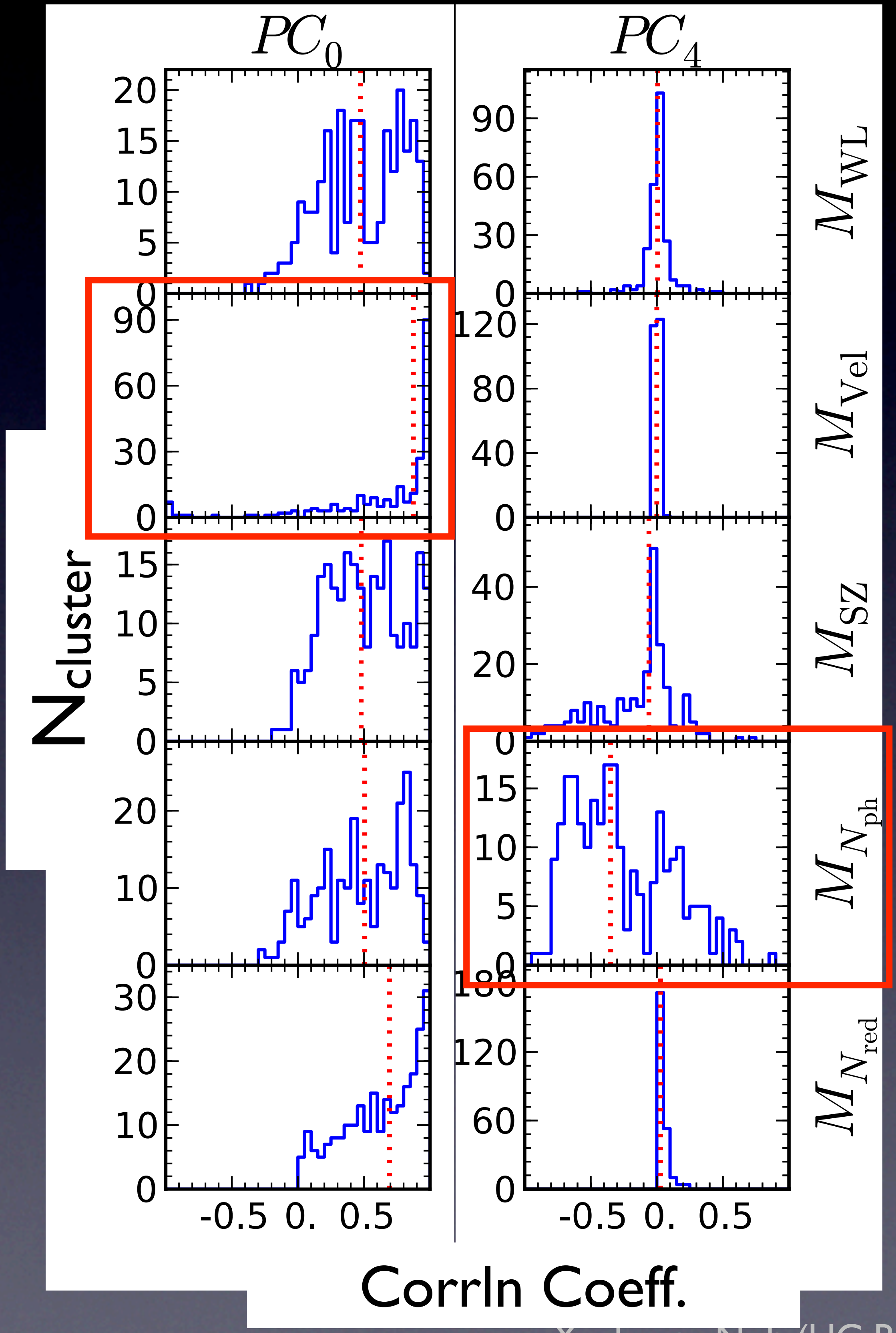
PCA for Cluster Observables



- PC0 accounts for 70% of total variance on average
  - $\hat{PC0} \sim 0.42M_{red} + 0.14M_{ph} + 0.19M_{sz} + 0.83M_{vel} + 0.29M_{wl}$
- Including PC0 and PC1 accounts for 95% of total variance on average

PCs vs. Observables

- Velocity dispersion mass measurements show the largest correlation with PC0
- N_{phase} mass measurements show the largest correlation with PC4



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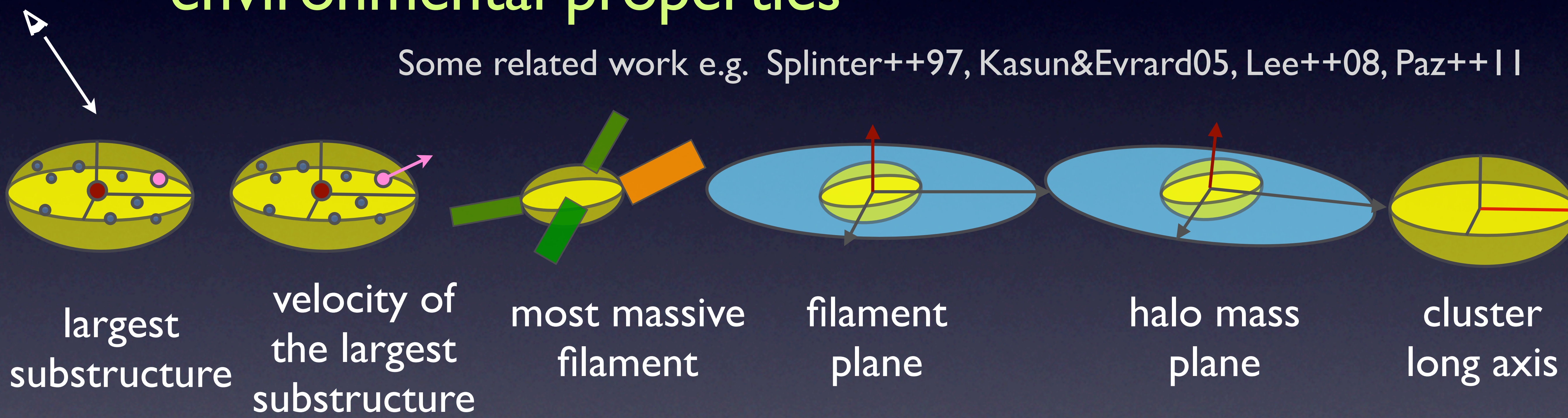
Cluster Properties depending on line-of-sight

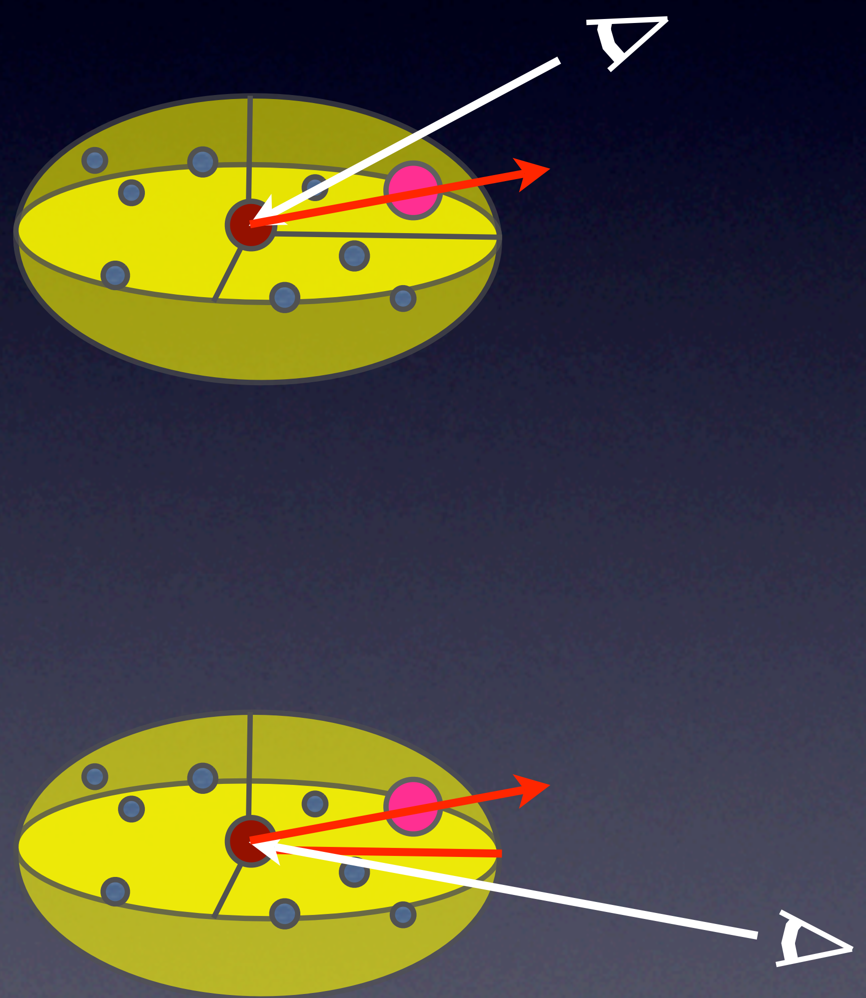
- Consider directional dependent intrinsic and environmental properties

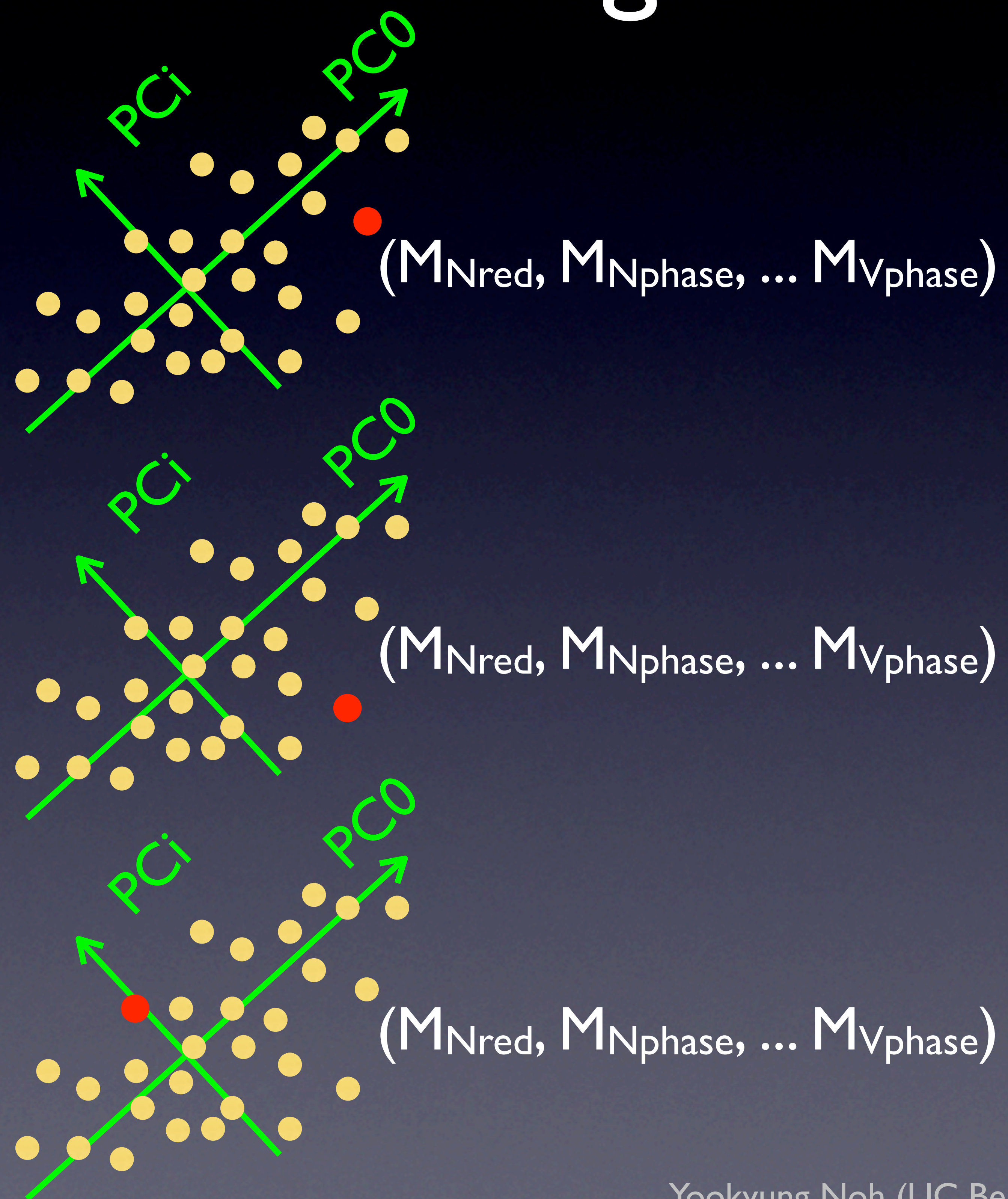
Some related work e.g. Splinter++97, Kasun&Evrard05, Lee++08, Paz++11



Cluster Properties depending on line-of-sight

e.g.

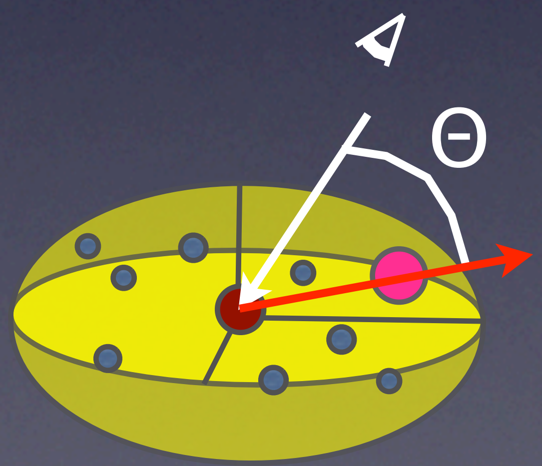




Correlation with line-of-sight dependent Properties

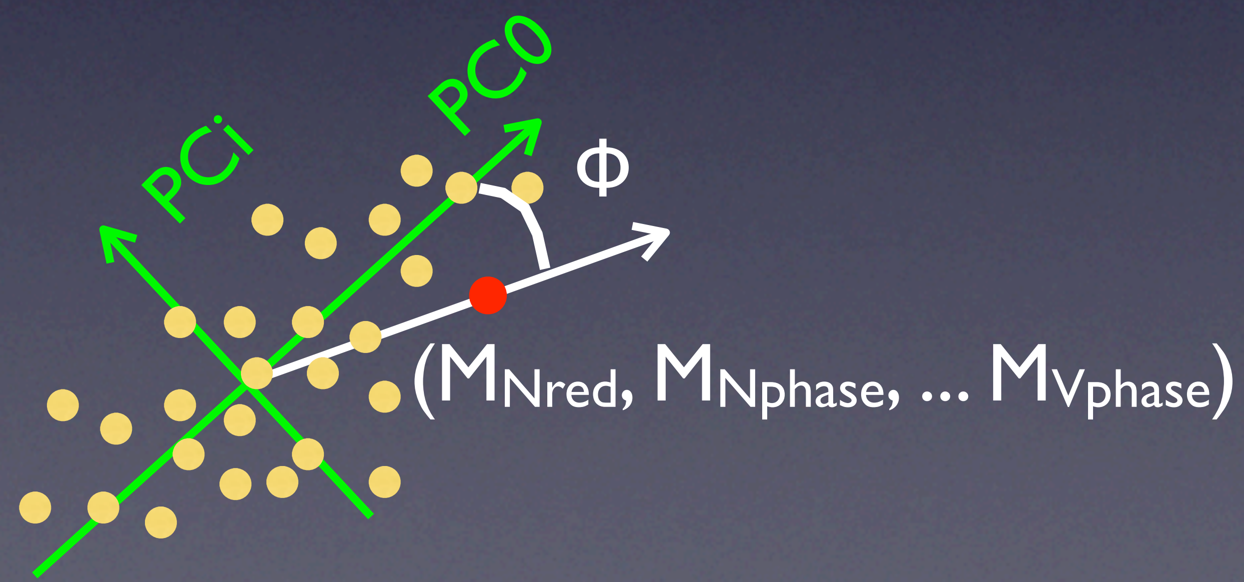
- Calculate the correlations between
  - |cosΘ| between line-of-sight direction and each of directional properties
  - cos Φ of the mass scatter along each line-of-sight to PC0 direction

e.g.



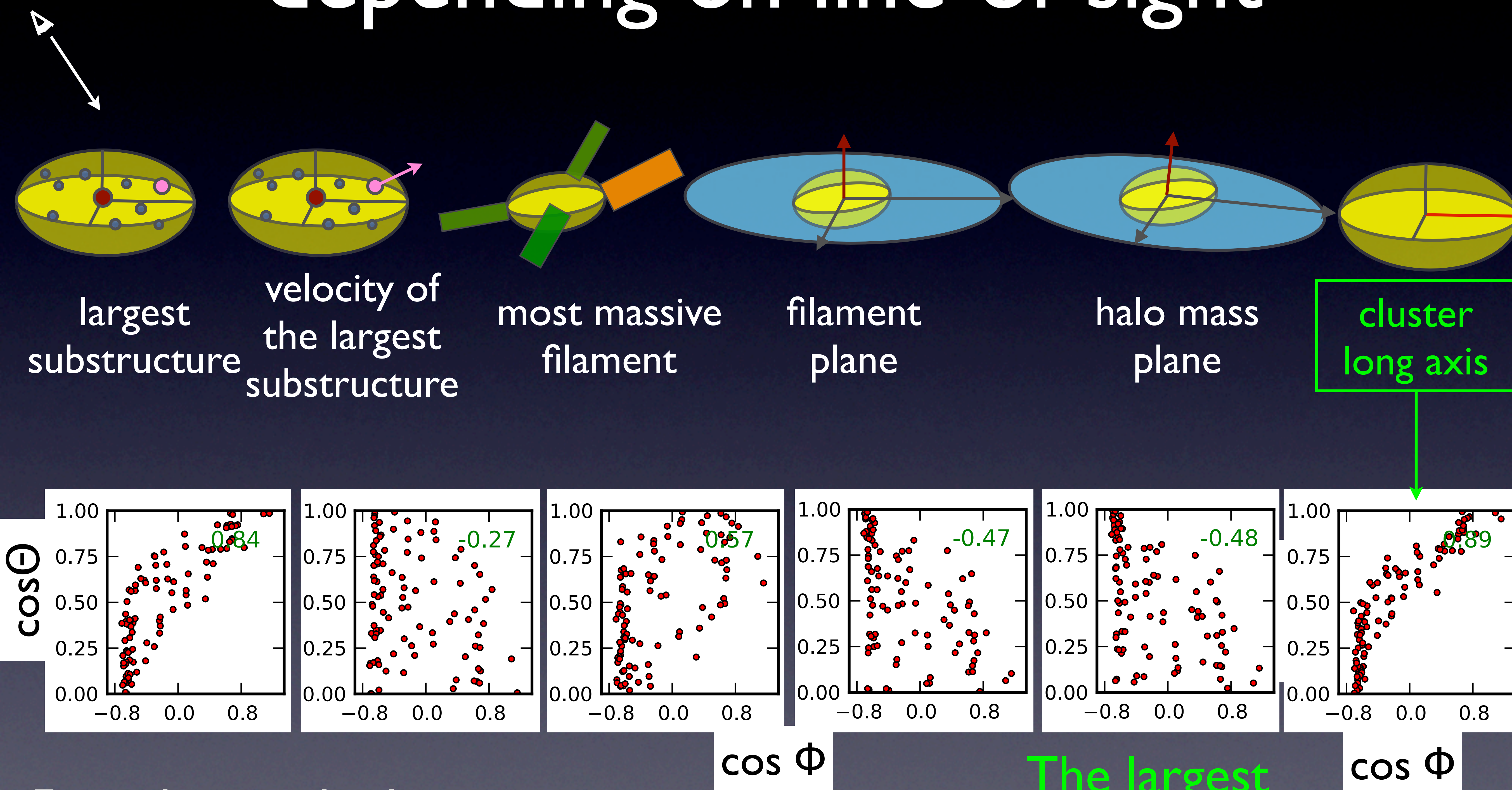
The angle with the direction of the largest substructure

and



Noh & Cohn MNRAS (2012)

Cluster Properties depending on line-of-sight



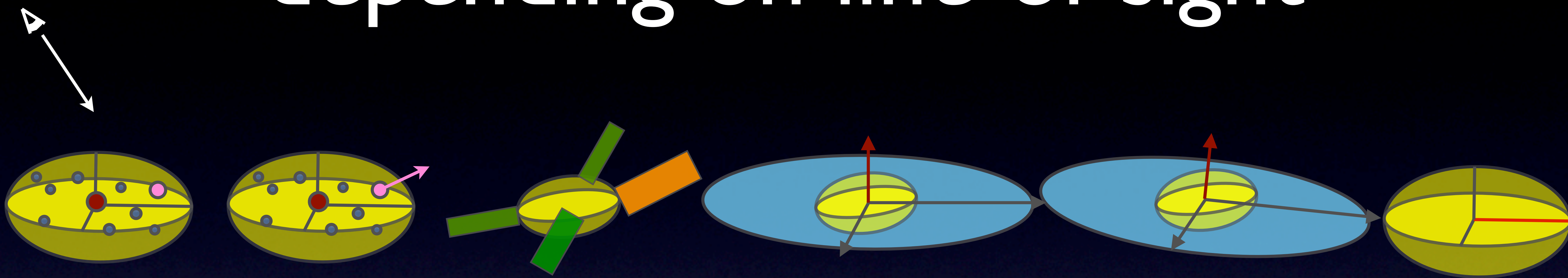
The largest correlation/covariance

Example: a single cluster

Yookyung Noh (UC Berkeley)

Noh & Cohn MNRAS (2012)

Cluster Properties depending on line-of-sight



largest substructure

velocity of the largest substructure

most massive filament

filament plane

halo mass plane

cluster long axis

Next largest correlation/ covariance

Many of these axes are close to each other in direction

The largest correlation/covariance
➔ observing along long axis has largest contribution from PC0

Correlations with the long axis and mass scatters have been discussed in e.g. Becker & Kravtsov 11, Feroz & Hobson 12

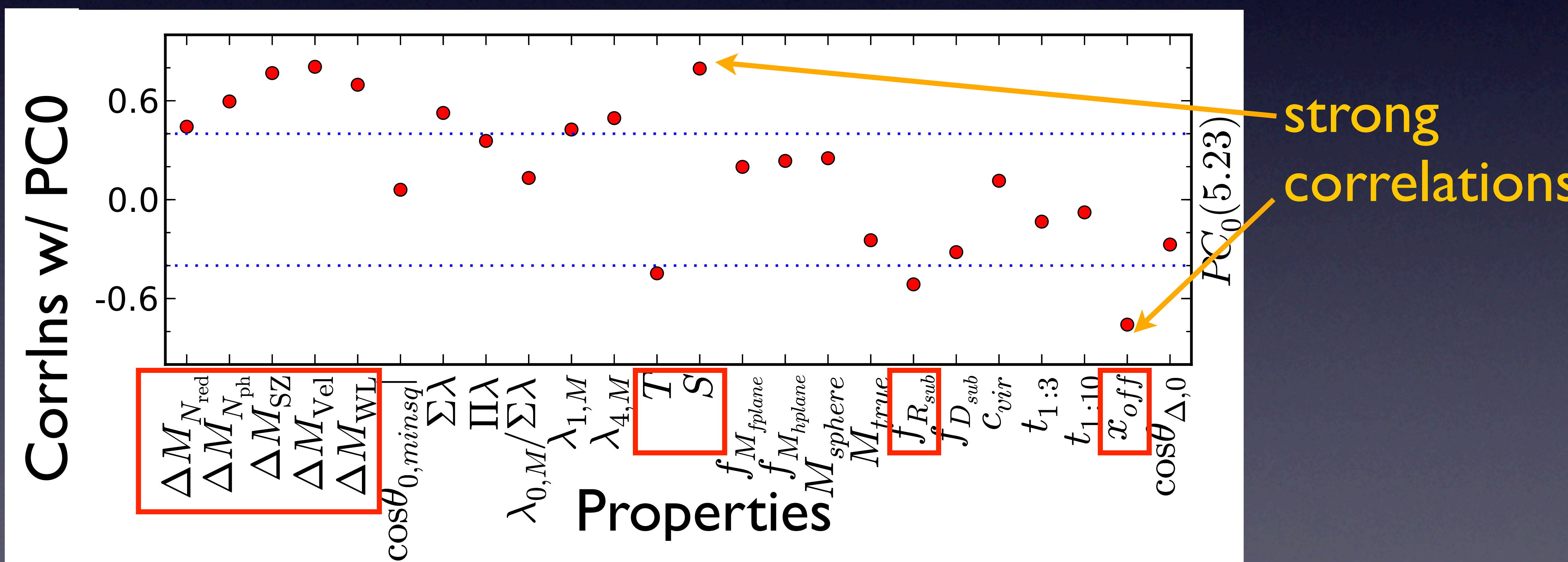
PCA for Ensemble of Clusters

- Calculate PC's for scalar properties
  Earlier related work: Jeeson-Daniel++, Einasto++, Skibba&Maccio(11)
  - Mass scatter properties: average scatter (i.e. $[\langle M_{obs}\rangle - M_{true}]/M_{true}$), PC's from mass scatter PCA, etc.
  - Physical properties: mass fraction in filament plane, richness fraction in biggest sub halos, triaxiality, etc.
- PC0 accounts for ~20% of total variance
  - Including up to PC4 accounts for ~50% of total variance

Noh & Cohn MNRAS (2012)

PCA for Ensemble of Clusters

- PC0 is strongly correlated with the average offsets in mass measurements and shape parameters



Summary

- Filament distributions around clusters are planar
  - A source of scatter in mass measurements
- Scatters in different mass measurements are often correlated with each other
  - can cause biases, error, underestimates, etc. if not taken into account
  - Due to the shared physical origins of scatter: Cluster long axis is most correlated with PC0
  - Analyzed using PCA: which combinations of scatter tend to occur together?

Summary

- Calibrating the scatters and their correlations requires simulations which faithfully reproduce observables, systematics and selection function