Cluster ellipticity with weak gravitational lensing shear

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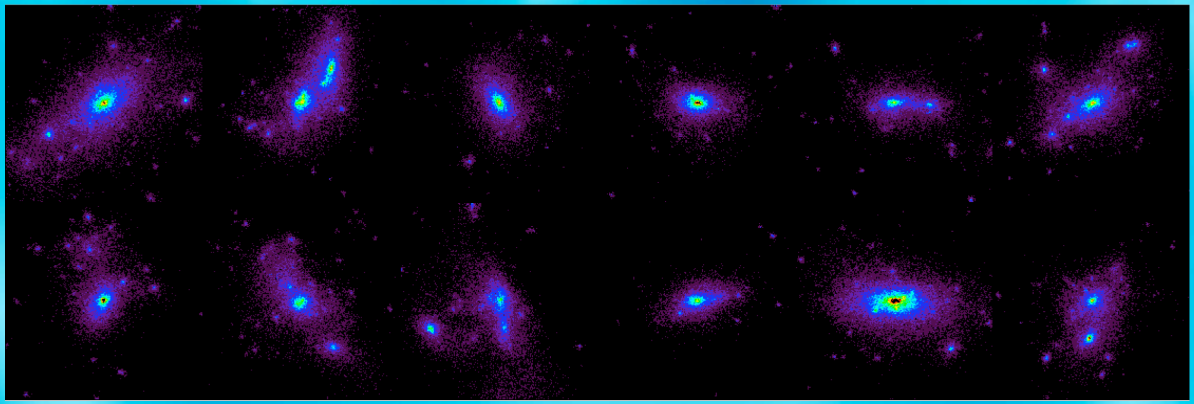
Overview

- **Motivation**: why study cluster ellipticity?
- **Method**: how can we observe cluster ellipticity with weak lensing?
- **Complications**: how does real life muck up the observation?
- **Results**: what can we learn from this type of observation?
- **Future**: what issues remain unresolved?

Motivation

- Halo flattening has long been a prediction of N-body simulations of structure formation



- Observation of asphericity will provide more evidence for believing our theories of structure formation
- Interesting results of a recent hydrodynamic simulation suggest that baryonic physics can influence the overall shape of the halo, reducing the triaxiality by 20%
- Observationally quantifying the extent of ellipticity could help resolve the debate

More motivation

- Sphericity is commonly assumed when associating proxies with mass
  - Observational calibration can help quantify errors in derived masses
- Observation of dark matter halo shape has been successfully implemented on galactic scales with galaxy-galaxy lensing (e.g. Hoekstra et. al.)
  - This suggests that a similar approach for galaxy clusters may be feasible

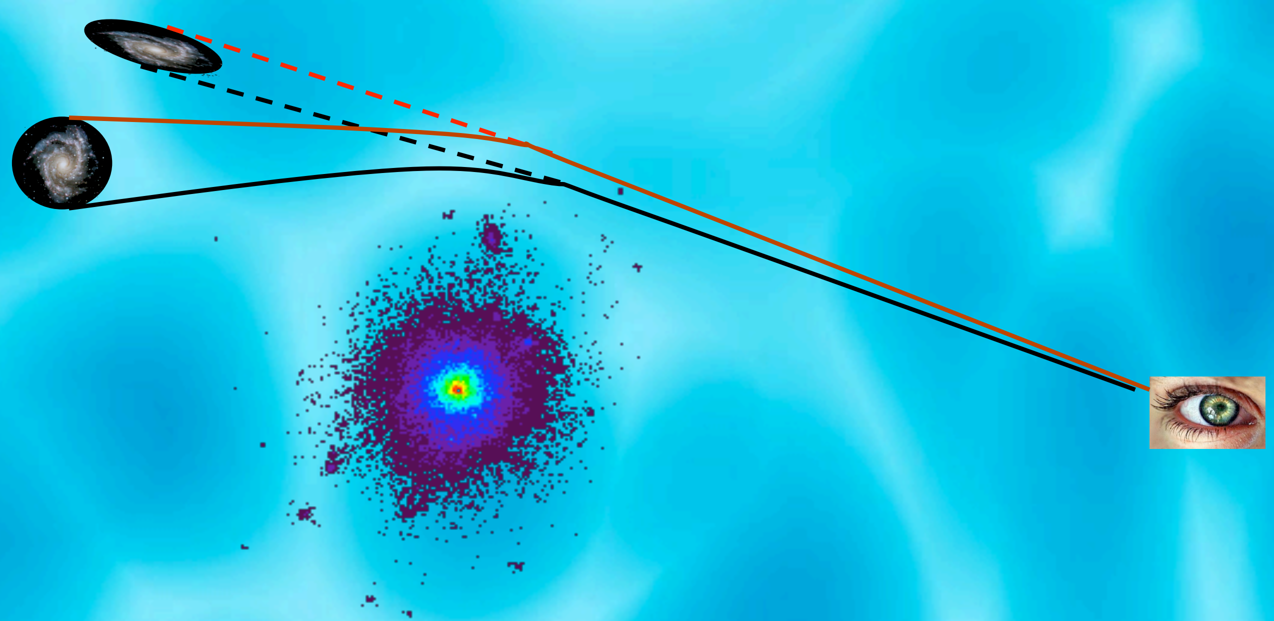
Even more motivation

- Why weak lensing?
  - A weak lensing approach is desirable because it is a direct measurement of the mass distribution
  - There is no need to postulate and calibrate a mass-observable relation to connect with theoretical predictions
  - Results can be compared to ellipticity estimators from X-ray and optical observations for consistency

Everyone motivated?

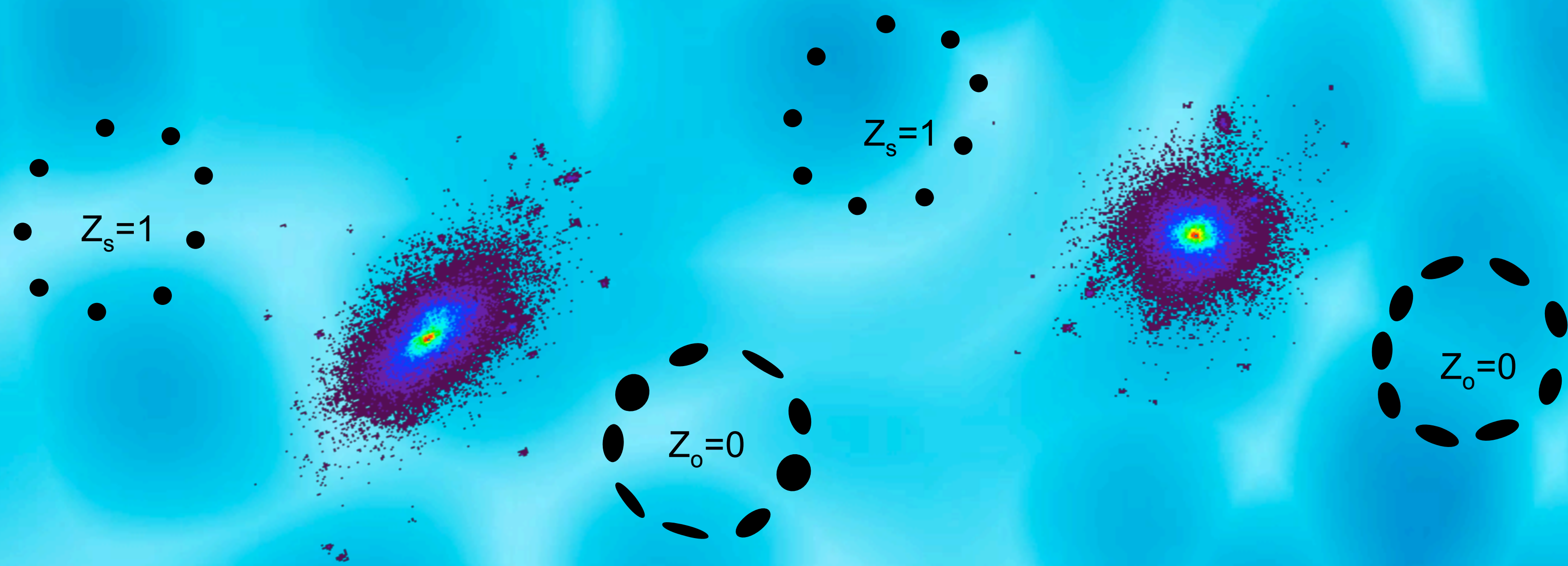
Weak Lensing in 20 seconds

- Massive objects in the foreground “repel” light rays coming from objects in the background
- Light rays that pass closer to the center of mass (black) are repelled more than light rays with a larger impact parameter (red)
- This results in a net shearing of a background object in the direction tangential to the center of mass



Lensing by an elliptical halo

- An elliptical foreground object will shear background galaxies more near the pointy ends

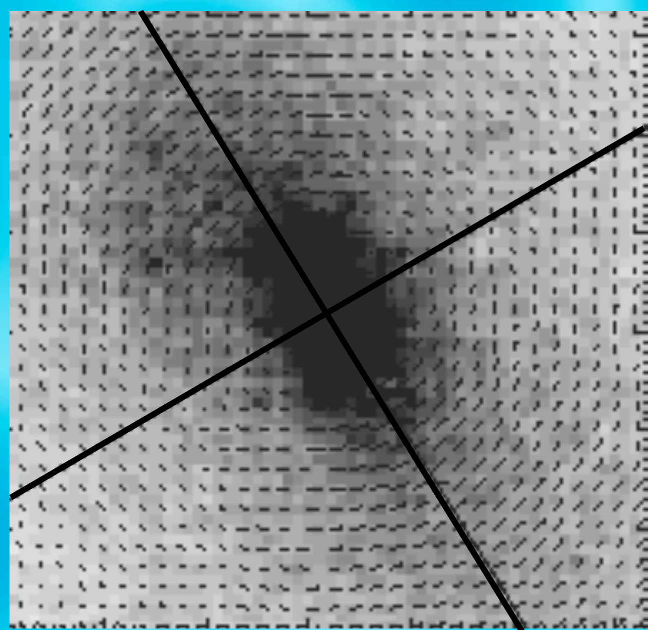


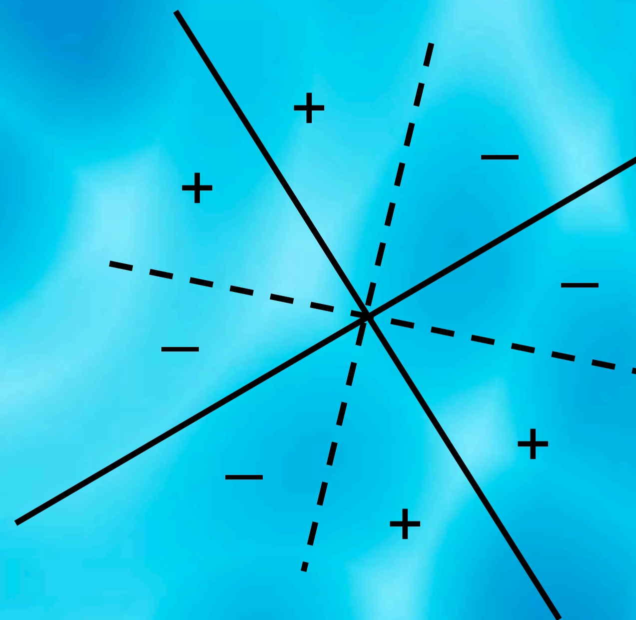
- Background galaxies are not a collection of perfect circles, but are elliptically shaped with random orientation
- A statistical measurement of 10s to 100s per square arcminute are needed to observe the shear

Method

- How can tangential shear measure ellipticity?

$\gamma_T(r, \phi)$





$W(\phi)$

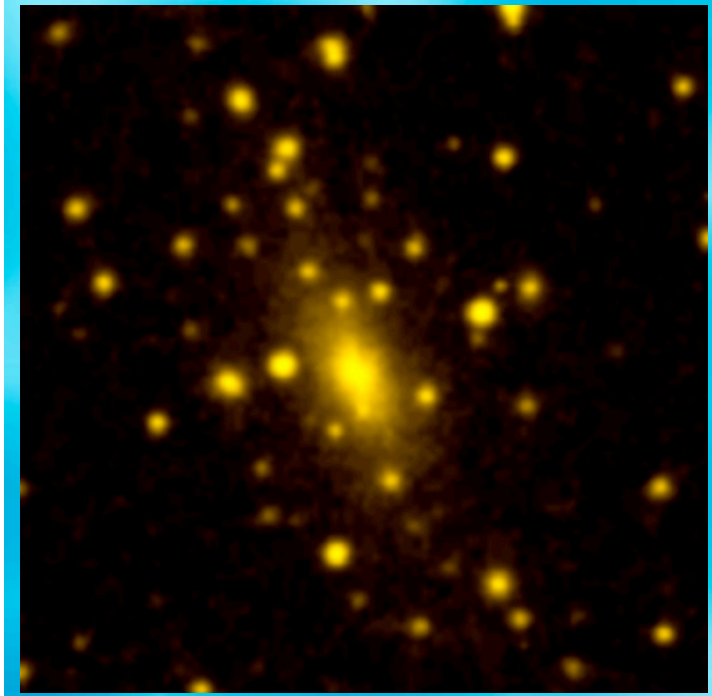
- A weighted integral of the tangential shear can measure this azimuthal variation

$$Q = \int_0^{2\pi} \int_{annulus} W(\phi) \cdot \gamma_T(r, \phi) \quad dr d\phi$$

The role of the BCG

- There is not sufficient S/N to determine the halo orientation (ϕ=0) from the weak lensing shear data
- There is evidence that the Brightest Cluster Galaxy is usually aligned with the orientation of the dark matter halo
- In dark matter simulations we must develop a way to estimate the direction indicated by observing the BCG

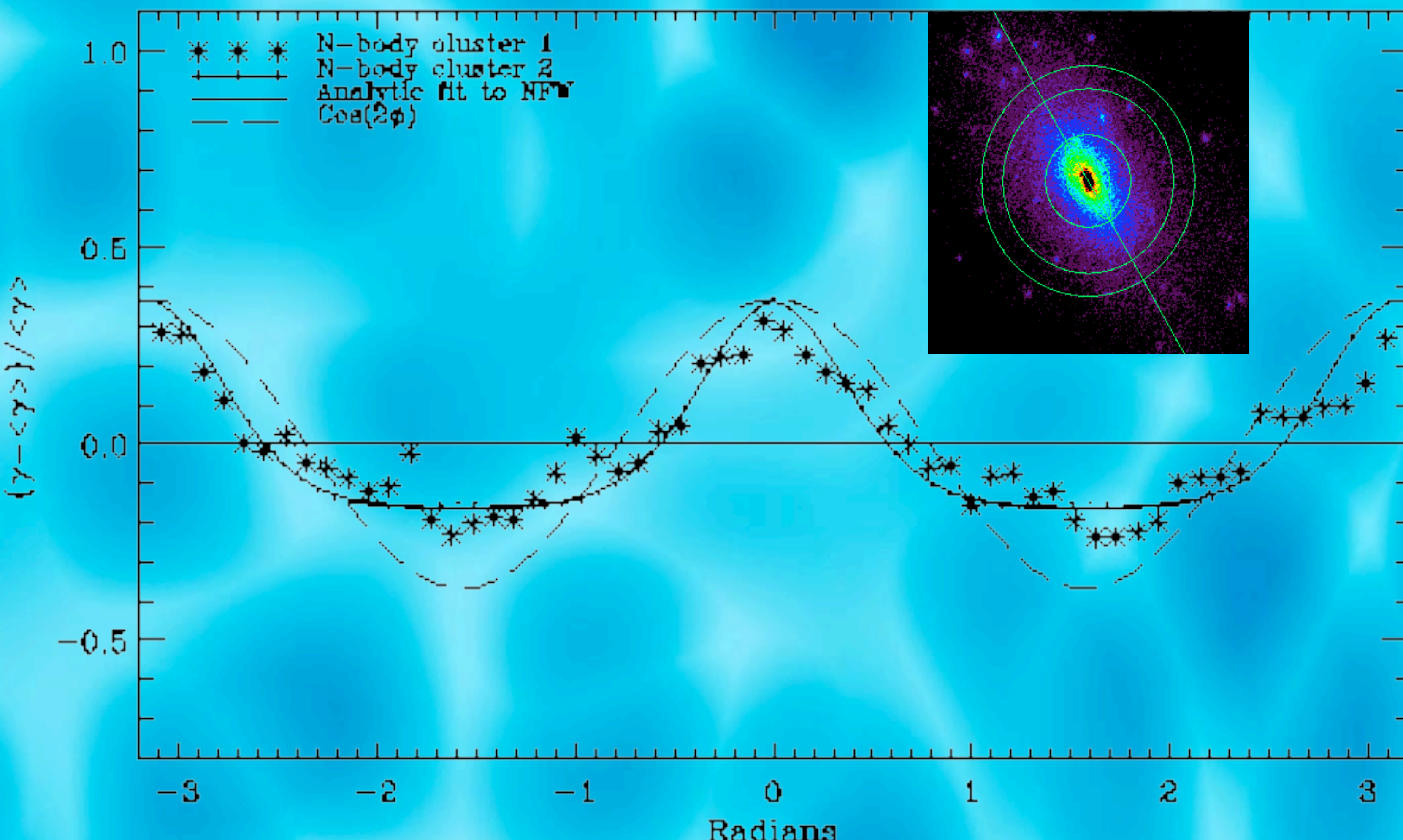
Abell-2029



- Used the moment of inertia tensor I_{ab} in the inner ~400 h^{-1}kpc to determine axis direction

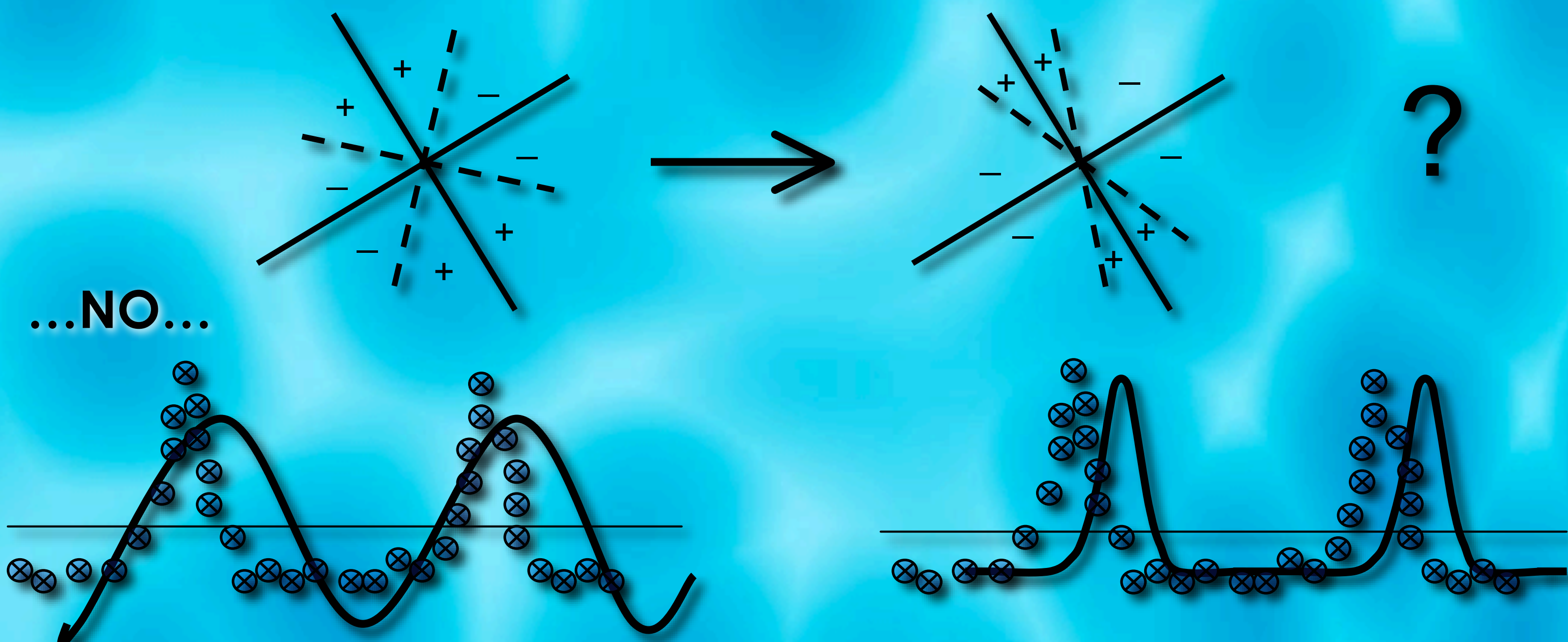
- Developed an iterative technique to converge on both axis ratio and orientation

Azimuthal profile of the shear



Optimizing the weight function

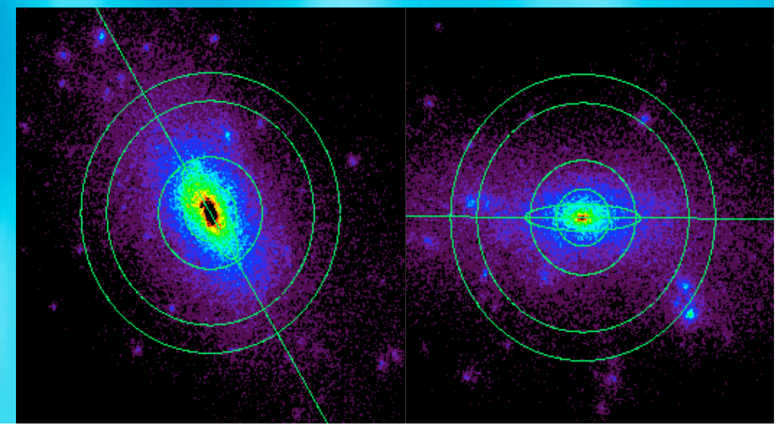
- The NFW clusters azimuthal profile differs significantly from the weight function $W(\phi)=\cos(2\phi)$
- Do results improve if we used a matched weight function?

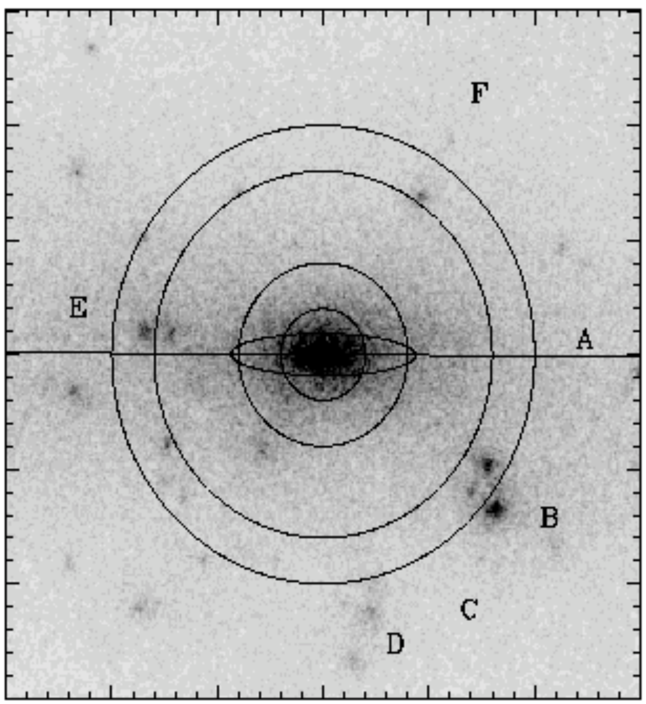


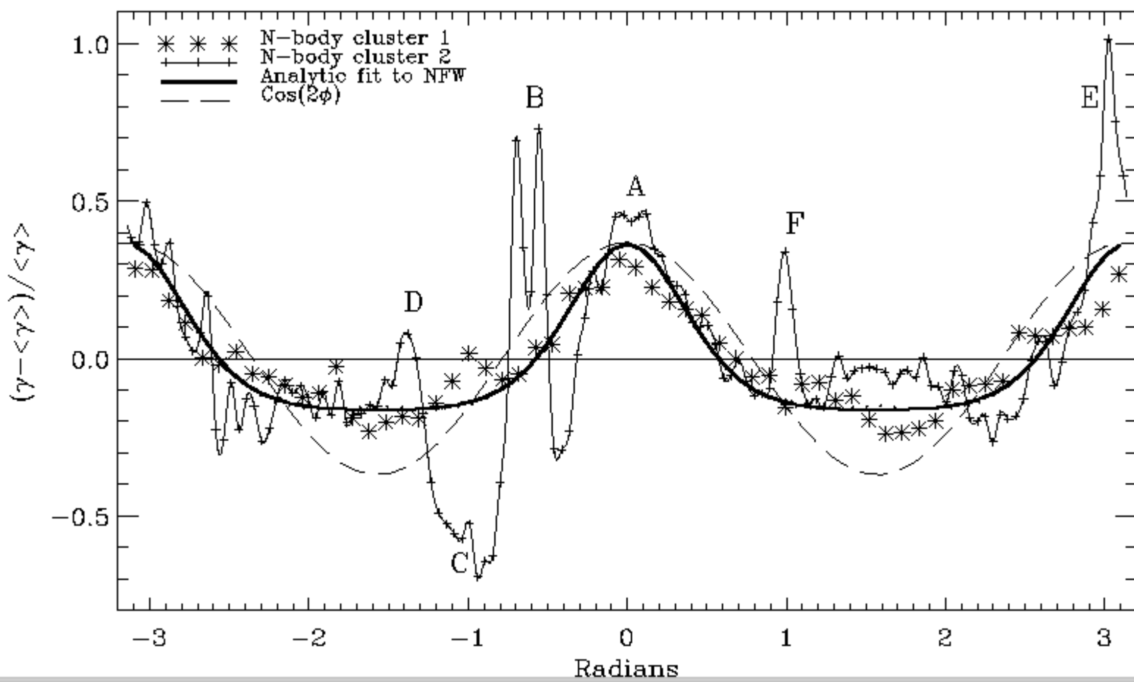
- $W(\phi)=\cos(2\phi)$ performs better than an NFW matched weight function

The impact of substructure

- Substructure in the observed annulus introduces large fluctuations in the shear profile
- Substructure near the center causes misalignment with the DM halo

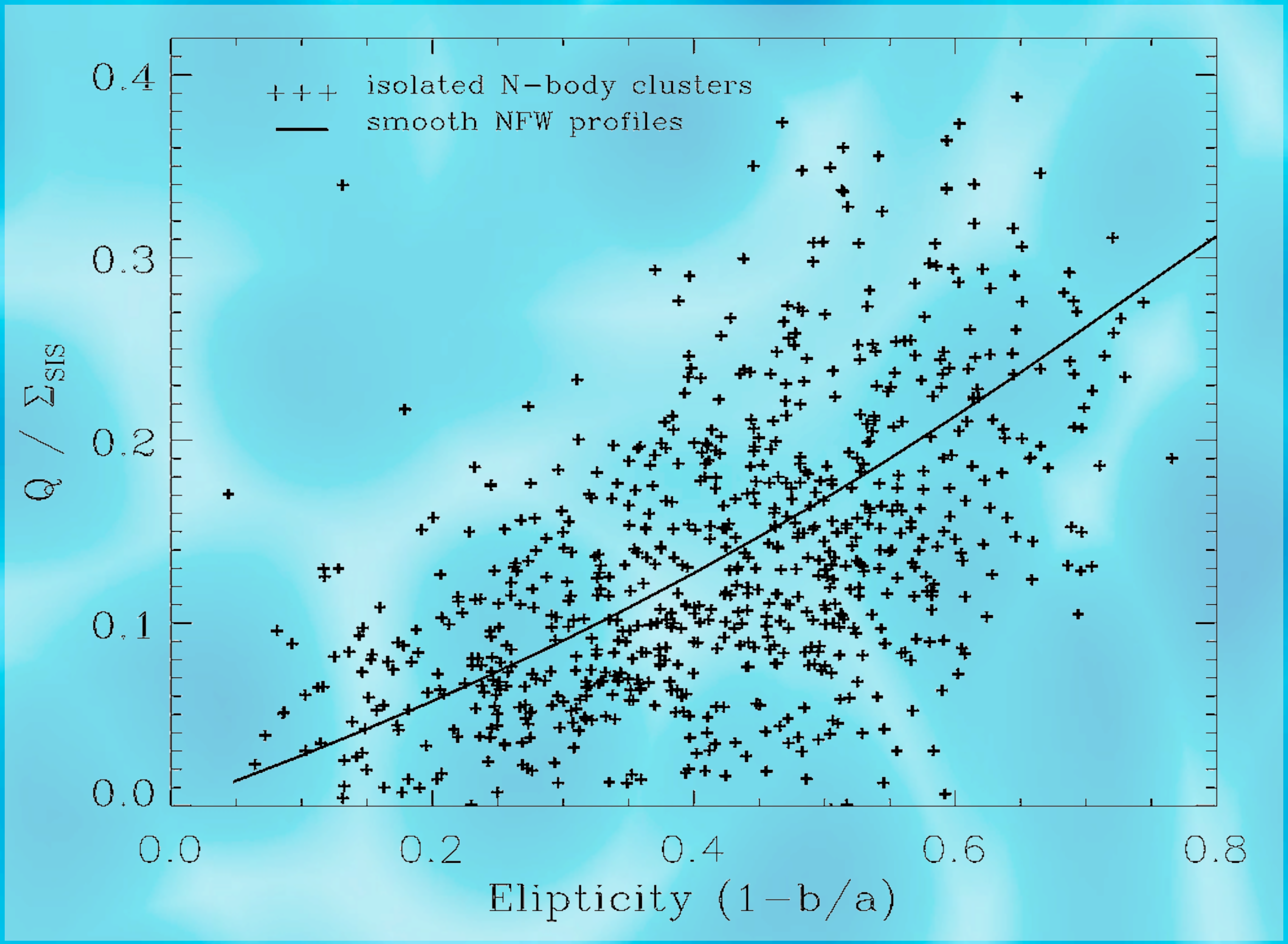






Q versus ellipticity from I_{ab}

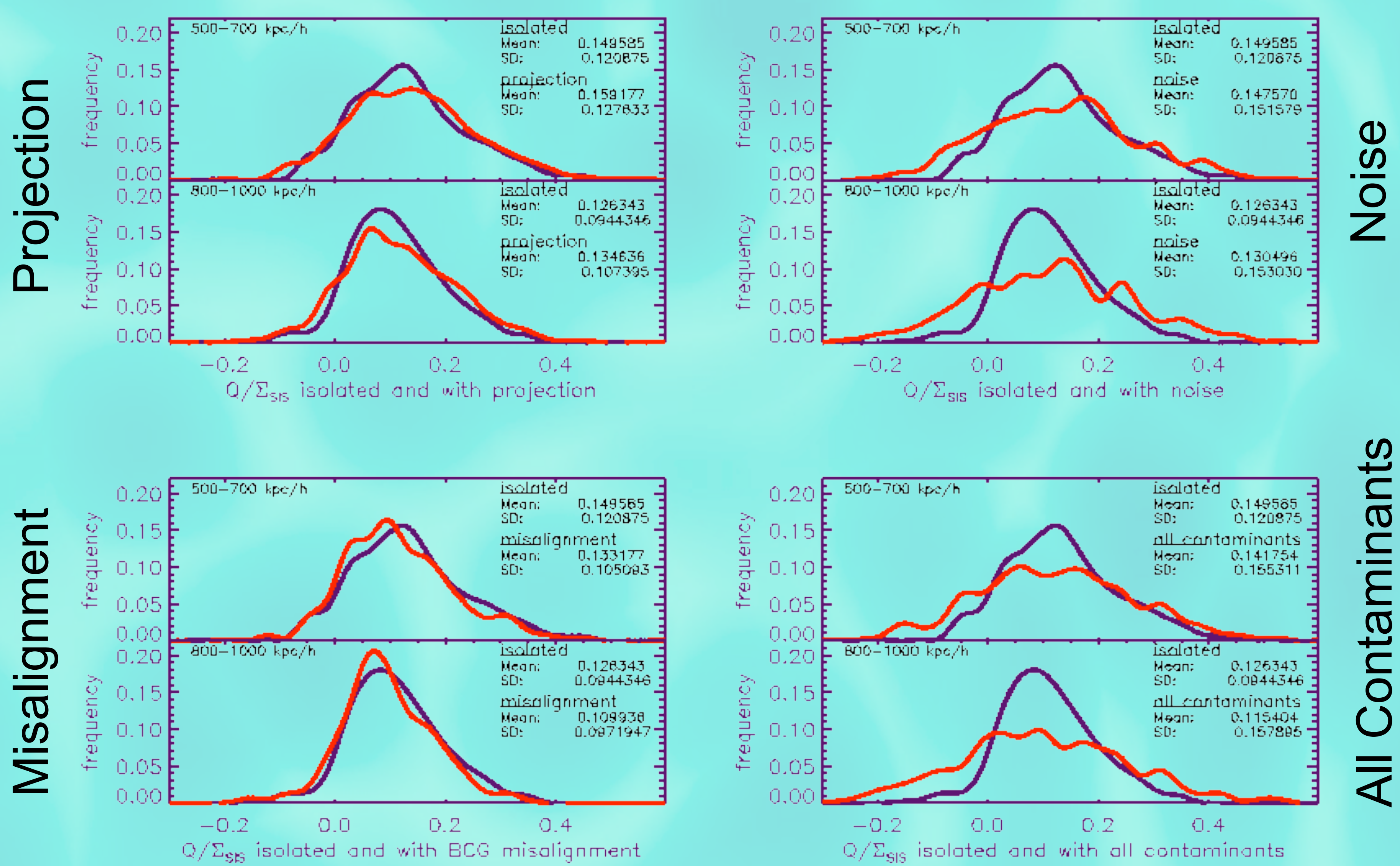
- Because of substructure, there is a large intrinsic scatter between the observable Q and ellipticity



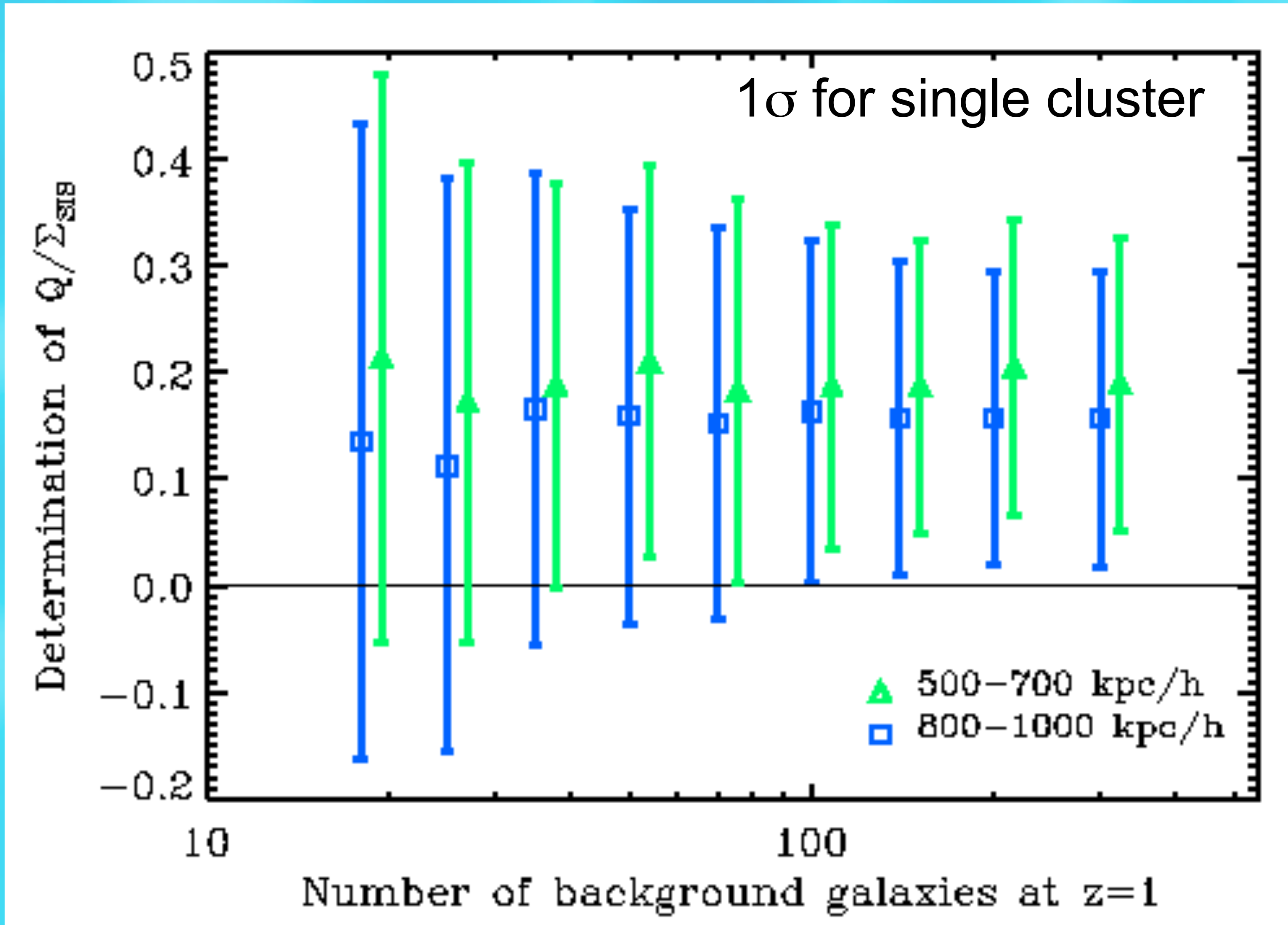
Mock Observations

- Quantifying the utility of the observable requires investigation of potential contaminants
  - Projection in the light cone
    - Added light cone κ maps to isolated clusters
  - Misalignment of the BGC with the halo
    - Introduced a 15° rms scatter to direction of $\phi=0$
  - Observation Noise
    - Added $(\delta\gamma_T)_{rms}=0.2$ to maps
    - Investigated measurements with 25 and 100 background galaxies per arcminute

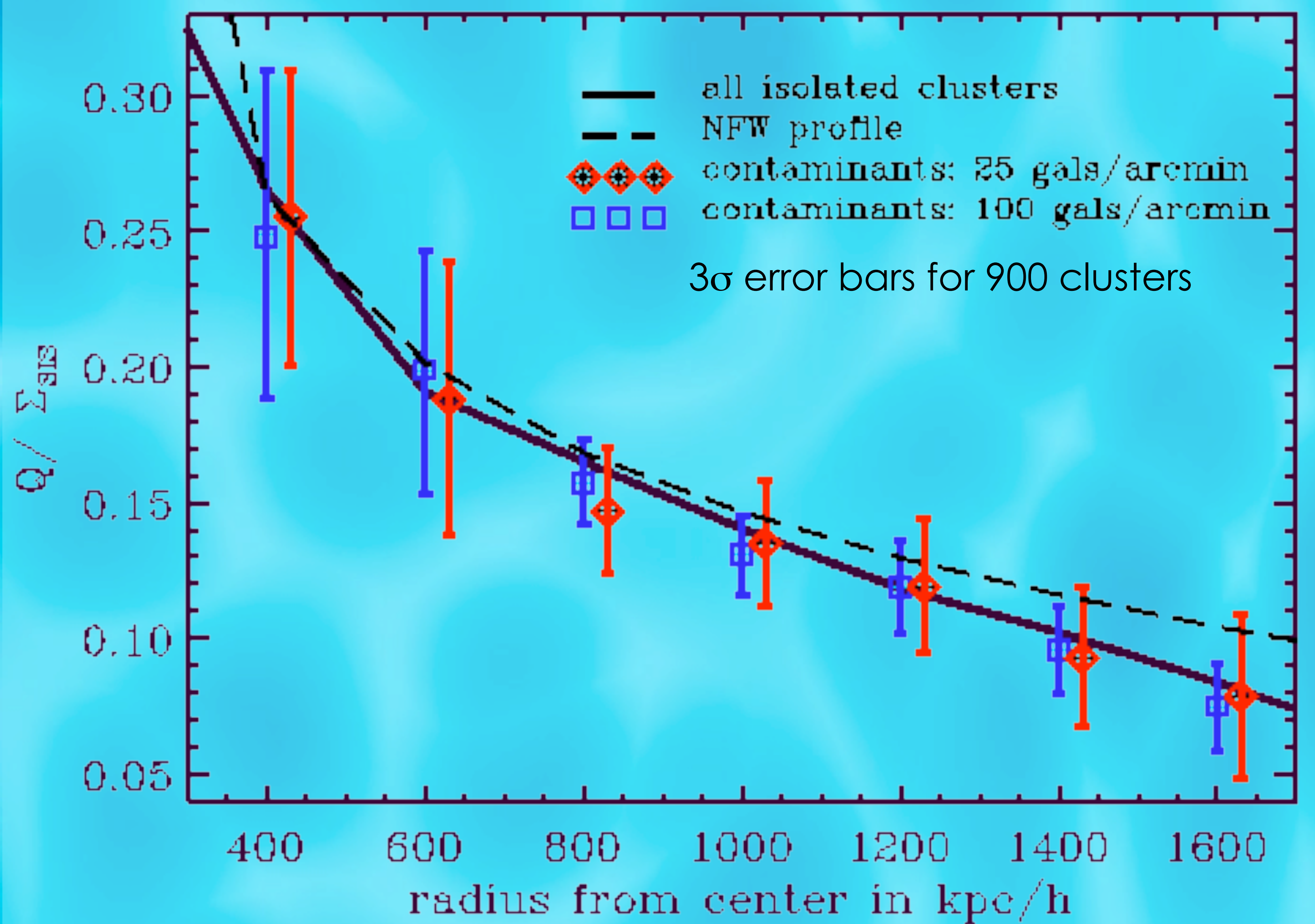
Impact of contaminants on the distribution of Q



Increasing Resolution



Radial Profile of Q



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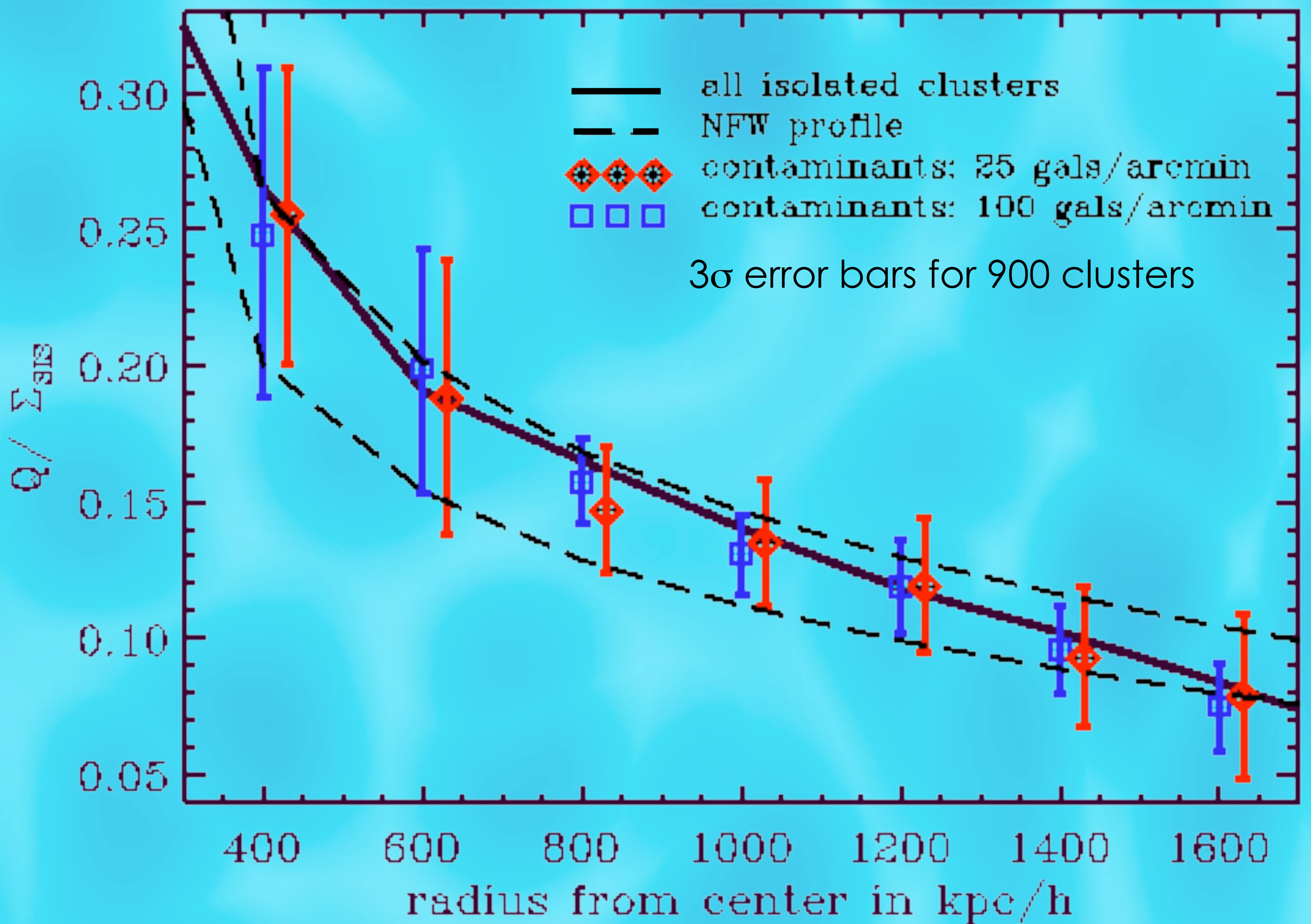
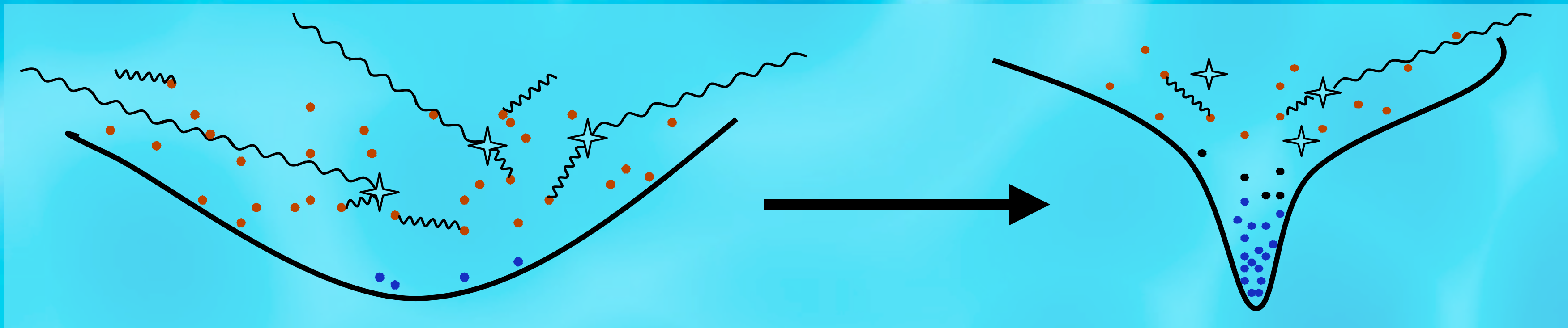


Can we really believe this?

- If overall halo shape were the dominant impact of baryons on this observable then YES… but…
- The observable is sensitive to the level of substructure in the cluster halo, and baryons are likely to change the character and amount of substructure



- Baryons may well cause an increase in intrinsic scatter through their influence on substructure
- Baryons may increase the influence of other structures in the light cone
- More research is needed to determine the net influence of baryons on this observable

Summary

- Moments of the tangential shear from gravitational lensing can effectively be used to study the lensing cluster ellipticities
- Substructure is found to heavily influence the signal
- Because of complications such as line of sight projections, misalignment of the central galaxy, and noise in the observation, many clusters will have to averaged to study cluster shape
- The influence of baryons is not easily guessed from these results, but they are likely to be important

Implications for SNAP

- Our study demonstrates that observation noise is the dominant source of error in weak lensing measurements of halo shape
- Observations from a Space Based platform such as SNAP will be able to reach many more background galaxies than is practical from ground based observations
- A weak lensing survey with SNAP should obtain data of sufficient quality to make quantitative statistical measurements of cluster shape
- SNAP should be capable of determining whether halo shapes are consistent with the predictions of CDM simulations, or whether they are substantially rounder

Future Outlook

- Weak lensing surveys will likely be able to detect cluster asphericity with this technique
- Future space based experiments such as SNAP may have enough resolution to resolve debate on the extent of triaxiality
- More theory is needed before the efficacy of this technique can be quantified.

Happy Bastille Day