The Dark Matter Filament Between Abell 222 and Abell 223

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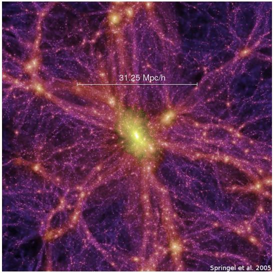
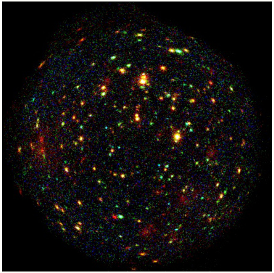
Take Home Message

We have the first weak-lensing detection of a large-scale structure filament. We use this to make the first direct measurement of the total mass of a filament and to constrain its hot gas fraction.

The Difficulty of Observing Filaments



N-body simulation

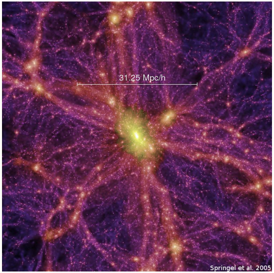


X-ray image

Optical image

Filaments are obvious in simulations, but not in observations.

The Difficulty of Observing Filaments



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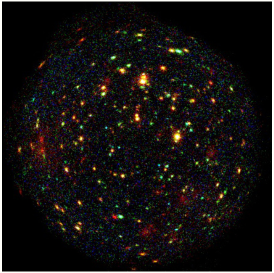


X-ray image

Optical image

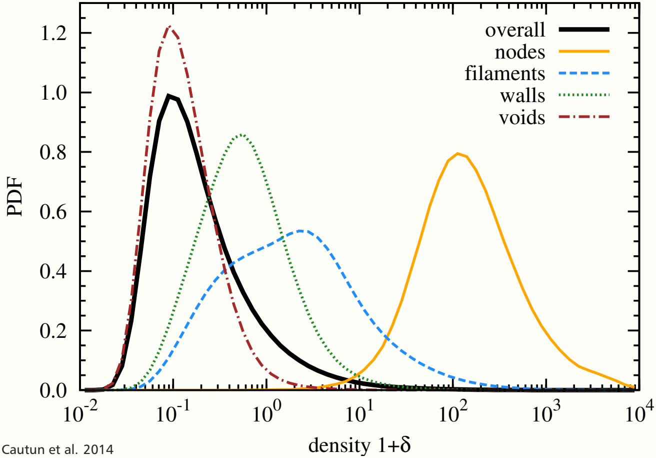
Filaments are obvious in simulations, but not in observations.

Cannot answer simple astrophysics questions without knowing filament Dark Matter content.

M/L ratio, gas fraction . . . This is where most galaxies live.

Need weak lensing to answer these.

A Problem of Density Contrast

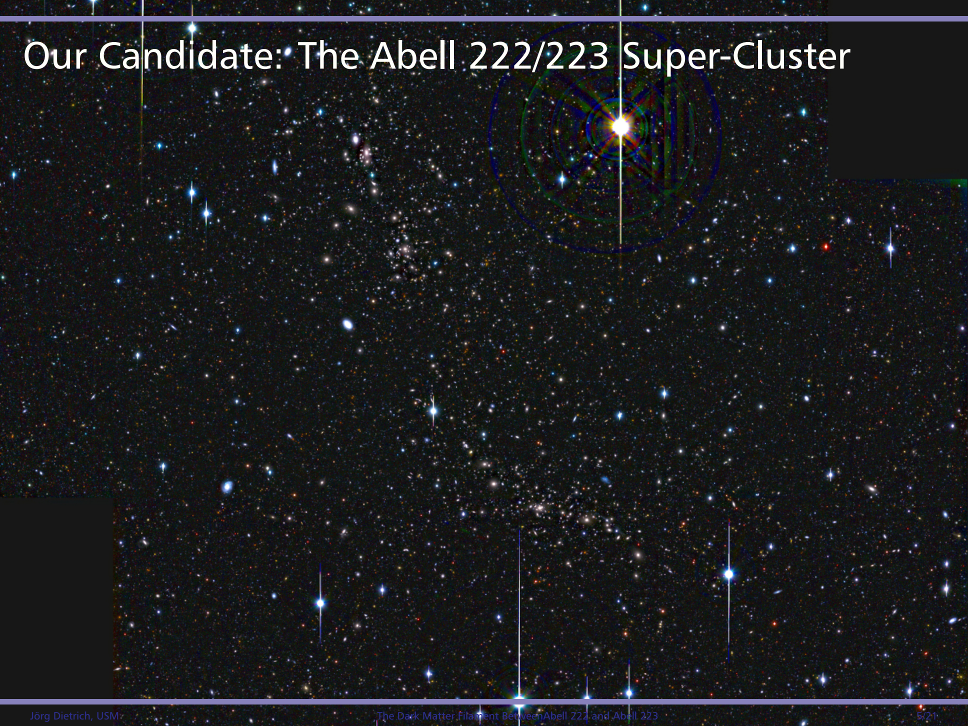


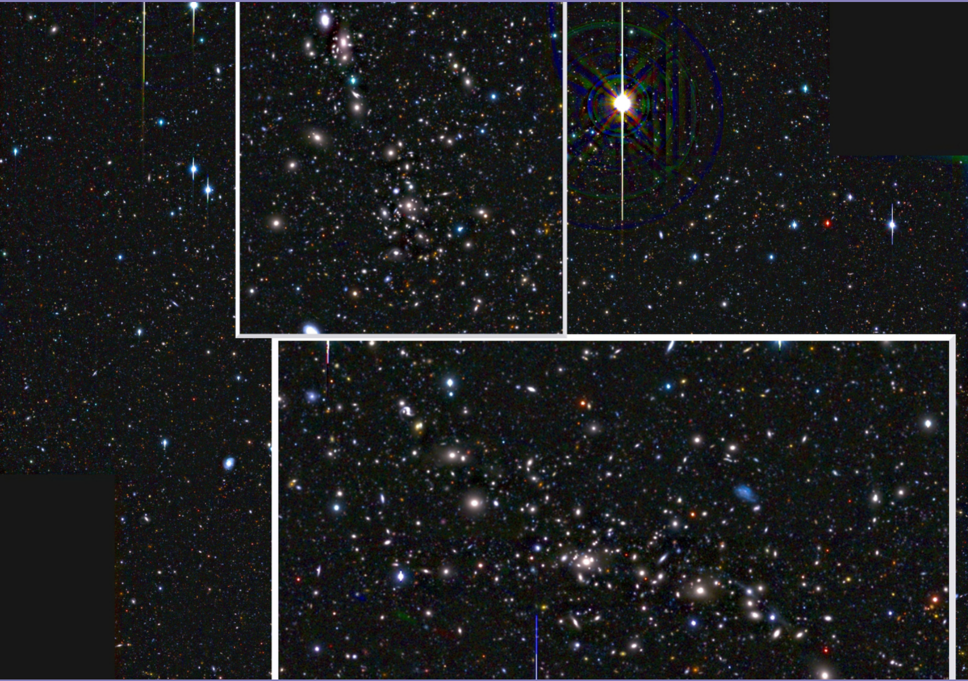
Cautun et al. 2014

Filaments more massive close to big clusters (Pogosyan 1998, BKP 1996).

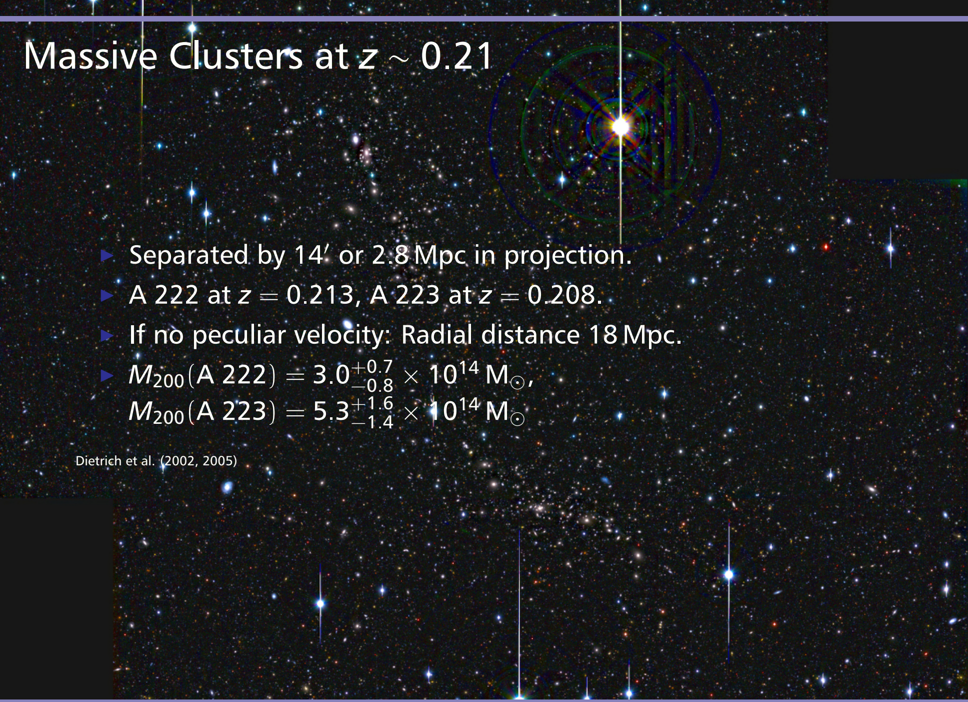
$\rightarrow$ Look between massive cluster pairs.

Our Candidate: The Abell 222/223 Super-Cluster





Massive Clusters at $z \sim 0.21$



- Separated by 14′ or 2.8 Mpc in projection.
- A 222 at $z = 0.213$, A 223 at $z = 0.208$.
- If no peculiar velocity: Radial distance 18 Mpc.
- $M_{200}(\mathrm{A}\ 222) = 3.0^{+0.7}_{-0.8} \times 10^{14}\,\mathrm{M}_\odot$,
  $M_{200}(\mathrm{A}\ 223) = 5.3^{+1.6}_{-1.4} \times 10^{14}\,\mathrm{M}_\odot$

Dietrich et al. (2002, 2005)

Galaxy Overdensity and 0.9 keV Gas Between A 222/3

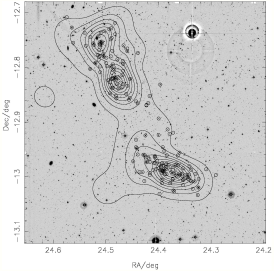
A&A 482, L29–L33 (2008)
DOI: 10.1051/0004-6361:200809599

Astronomy & Astrophysics

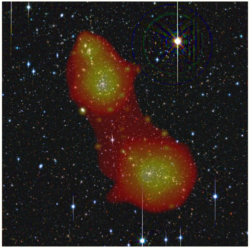
Letter to the Editor

Detection of hot gas in the filament connecting the clusters of galaxies Abell 222 and Abell 223

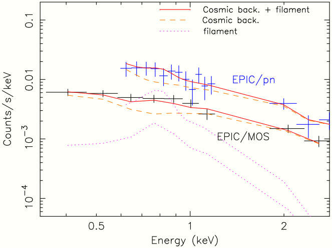
N. Werner[1], A. Finoguenov[2], J. S. Kaastra[1,3], A. Simionescu[2], J. P. Dietrich[4], J. Vink[3], and H. Böhringer[2]



Dietrich et al. 2002



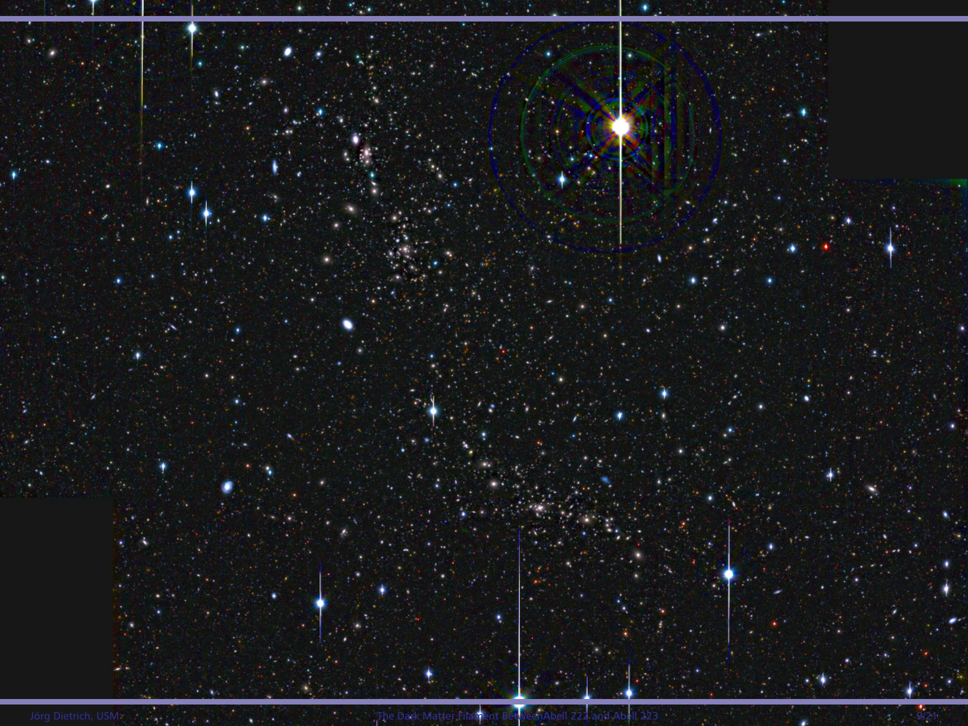
Werner et al. 2008

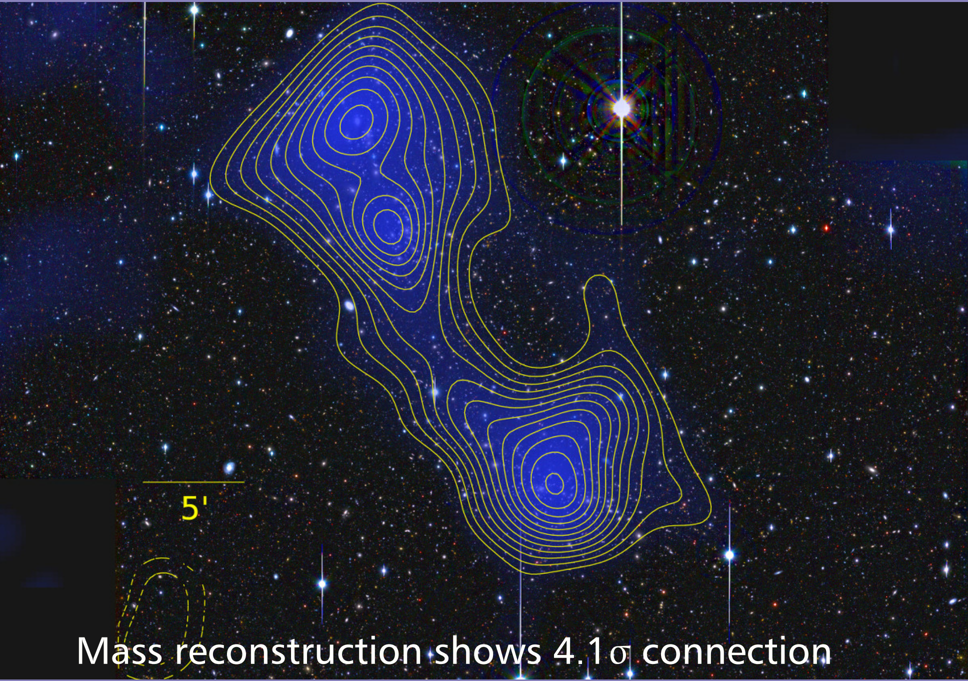


Low entropy gas (420 keV cm^2), not significantly shock heated.

Can we see the Dark Matter as well?

→ Use deep, excellent seeing SuprimeCam data.

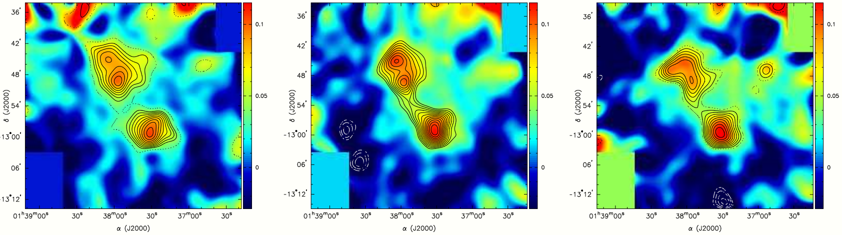




Mass reconstruction shows 4.1σ connection

Mass Bridge Seen in 3 Passbands

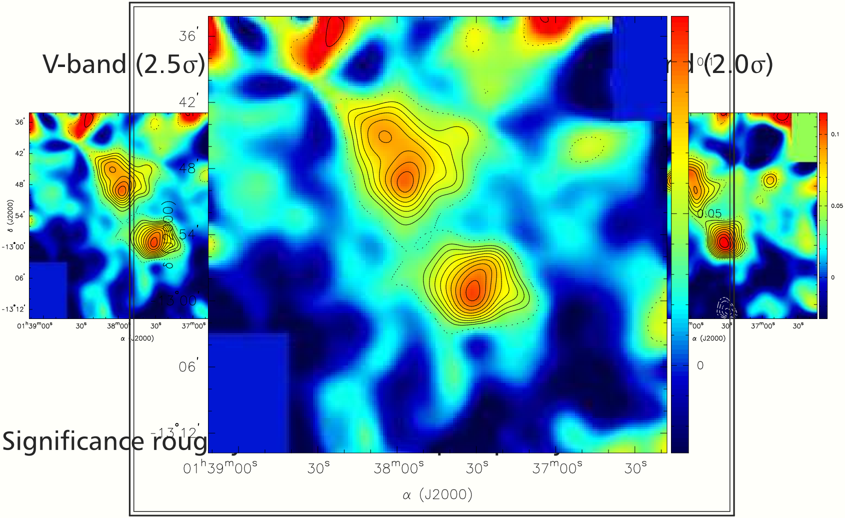
V-band (2.5σ) R-band (4.0σ) I-band (2.0σ)



Significance roughly follows data depth/quality.

Mass Bridge Seen in 3 Passbands

V-band (2.5σ) … d (2.0σ)



Significance roug…

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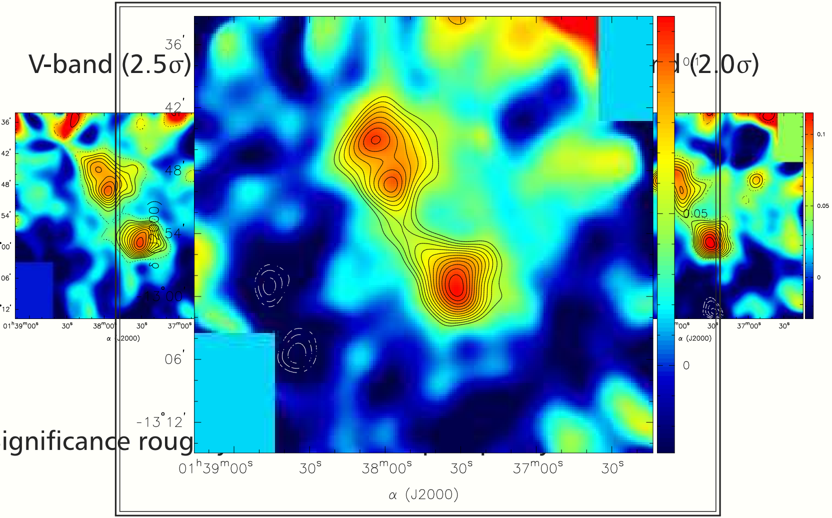

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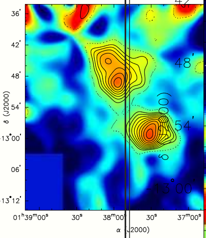

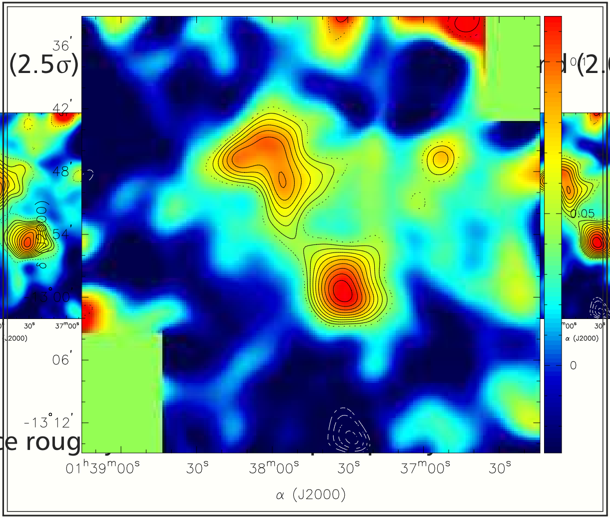

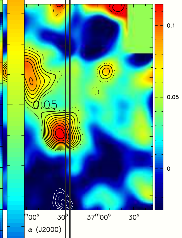

Significance roug…

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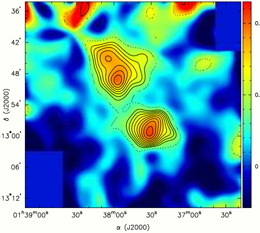
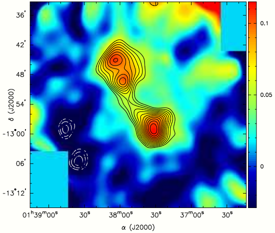
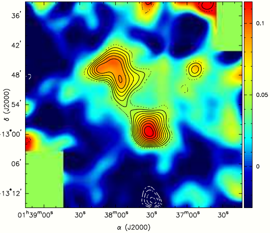
V-band (2.5σ)



R-band (4.0σ)

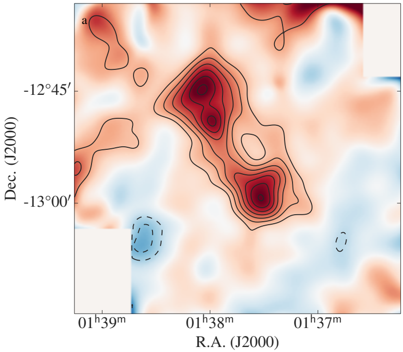


I-band (2.0σ)

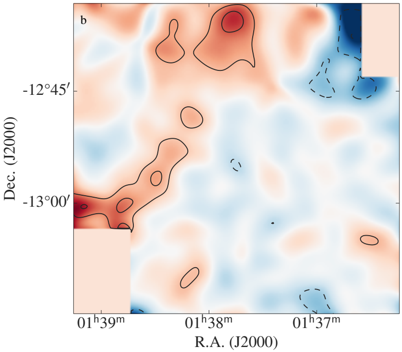


Significance roughly follows data depth/quality.

Systematics Under Control

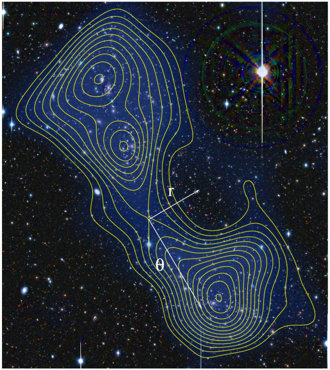


Signal

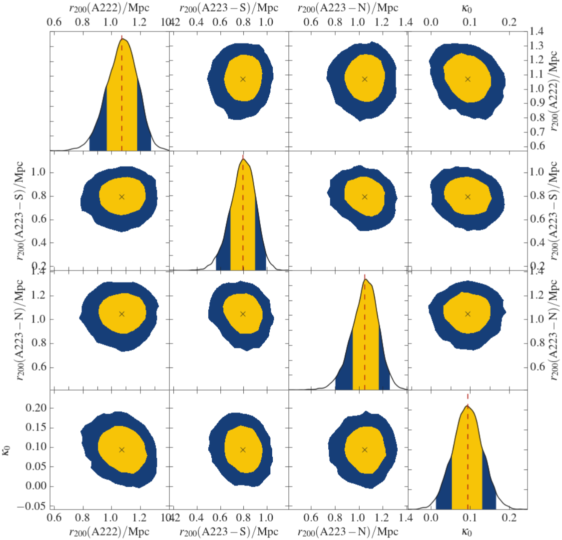


Control

Mass Bridge Not Caused By Overlapping Halos



$$\kappa(\theta, r) = \frac{\kappa_0}{1 + \exp\left[(|\theta| - \theta_l)/\sigma\right] + (r/r_c)^2}$$



- Parametric model: 3 spherical NFW halos + filament
- $\kappa > \kappa_{3NFW}$ for 99.8% of all points.

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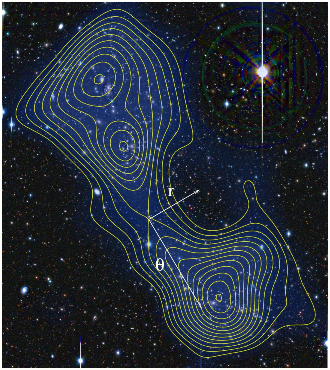

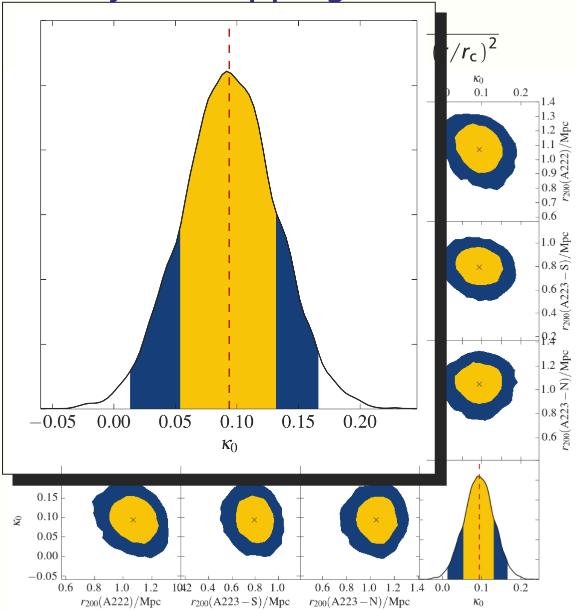

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  3 spherical NFW halos
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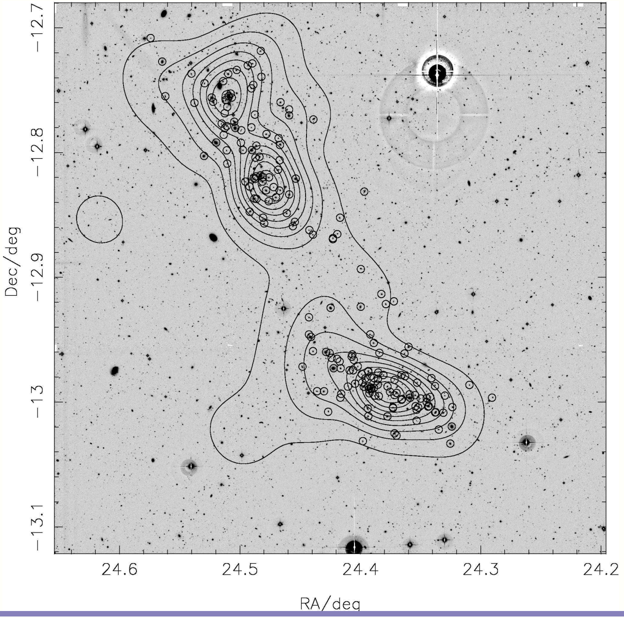
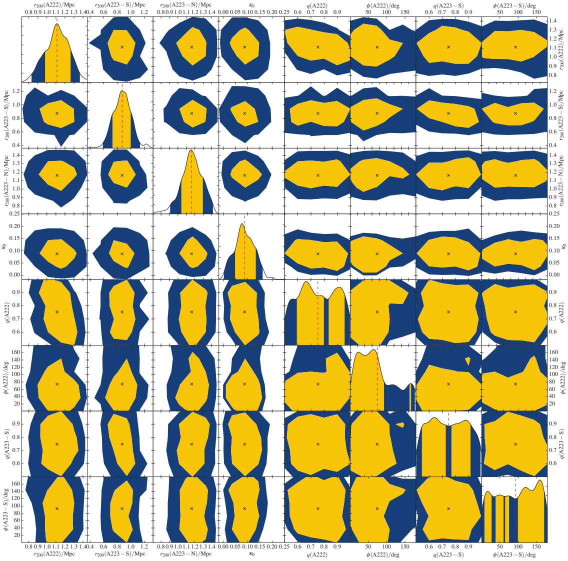
Clusters Are Elliptical, not Spherical



Data Cannot Constrain Halo Ellipticity



- Allow for ellipticity in A 222 & A 223-S.
- Significance almost unchanged: $\kappa > \kappa_{3NFW}$ for 99.3% of all points.

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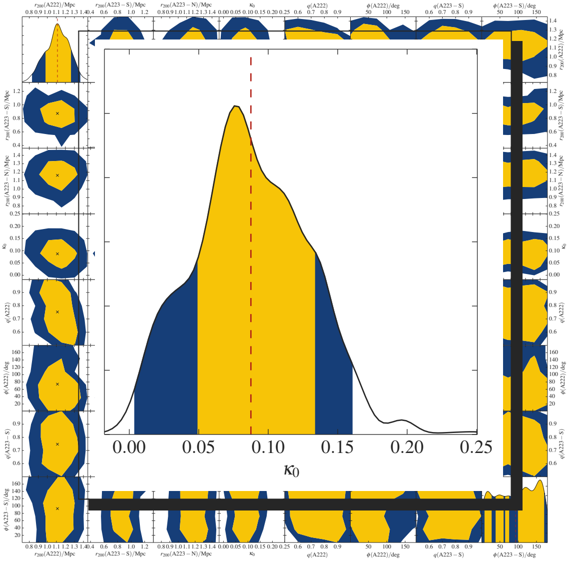

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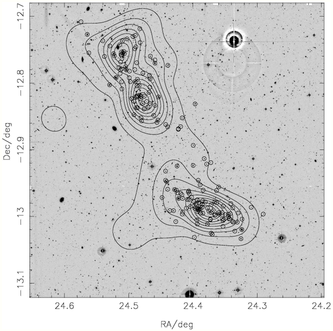
Ellipticity Follows Optical Data: Filament Still Needed



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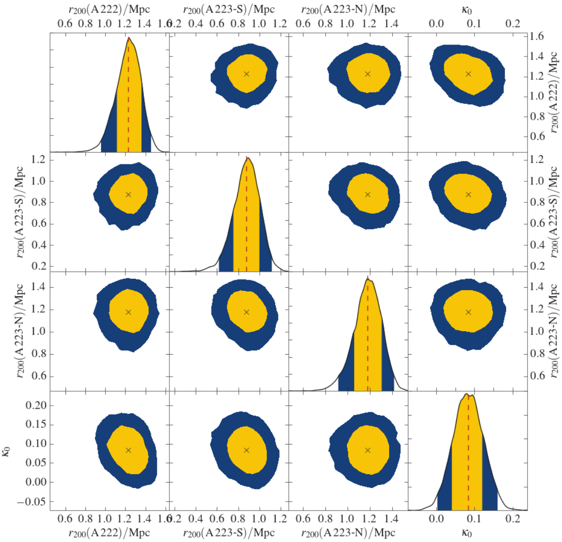
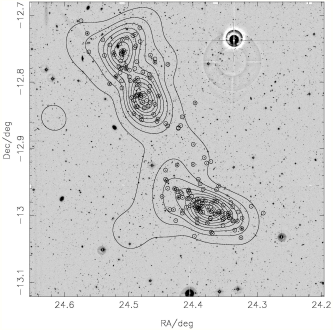
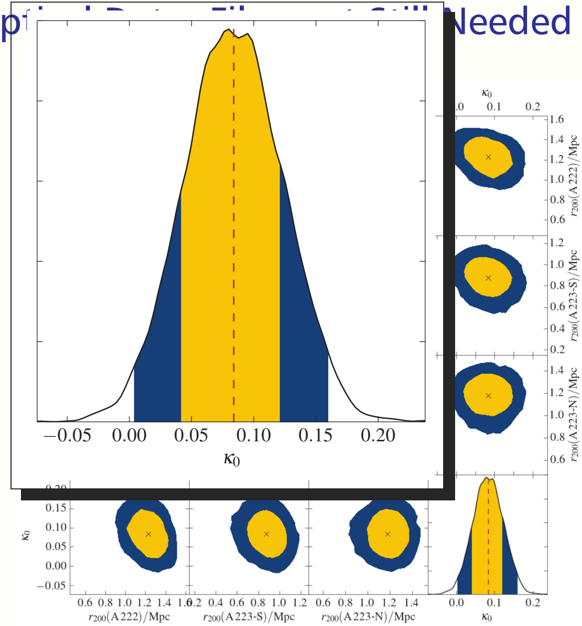
- $\Delta \ln \mathcal{L}$ prefers filament model at 96.6%.



Ellipticity Follows Opt… Needed





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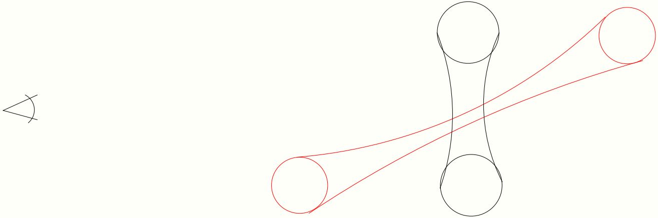
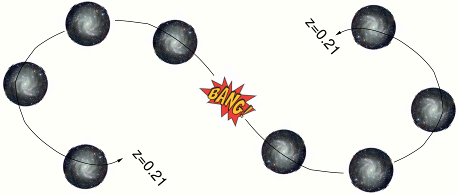
Geometry is important



- Is the redshift difference a cosmological difference or peculiar velocities?
- Looking along the major axis could boost the surface mass density to a detectable level.

Timing Argument: Redshift is Hubble Flow



Timing argument of Kahn & Woltjer (1959):

- Both cluster at the same point at $z = \infty$, radial orbit.
- Different masses and inclinations create observed $(\Delta z, \Delta\theta)$.
- Smallest mass without redshift component:
  $M_{\rm tot} = 2.86 \times 10^{15}\,{\rm M}_\odot \ll M_{\rm tot}^{\rm obs}$, inclination 46°.

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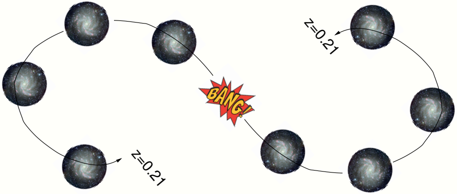

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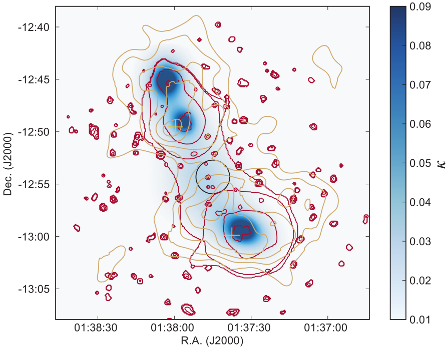
Consequences:

1. Δz is not peculiar velocity alone,
   significant line-of-sight component.
2. System not merging (matches low entropy of filament gas).

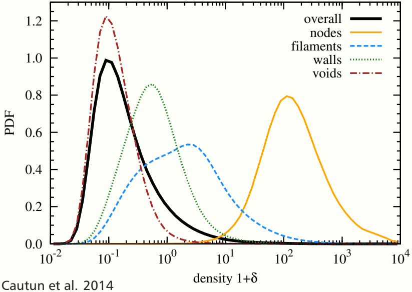
Filamentary Hot Gas Fraction: $f_g < 0.9$



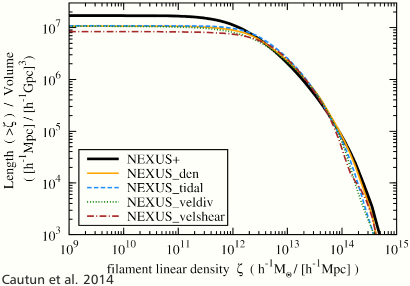
- Lensing mass inside black aperture: $M_{fil} = (6.5\text{–}9.8) \times 10^{13}\,M_\odot$.
- Gas mass inside same aperture: $M_{gas} < 5.8 \times 10^{12}(l/18\,\text{Mpc})\,M_\odot$.
- Hot gas fraction < 0.09.

The A 222/3 Filament is Unusual

But not for its environment



Cautun et al. 2014

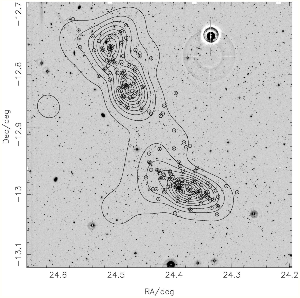


Cautun et al. 2014

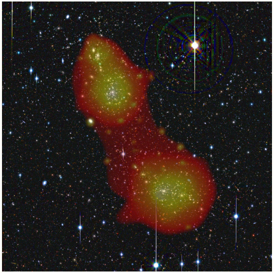
- $\rho_{\mathrm{fil}} = (150\text{–}300)\rho_{\mathrm{m}}$.
- Linear density $\xi = (3.6\text{–}5.4) \times 10^{12}\ M_{\odot}/\mathrm{Mpc}$.
- Hot gas fraction somewhat lower than value in clusters.
- Most gas too cold for X-ray detection.

Summary

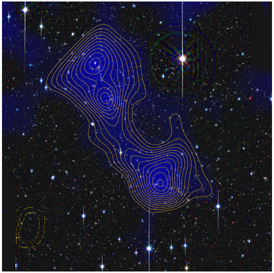
- First weak-lensing detection of a large-scale structure filament.
- Hot gas fraction within expectations.
- Filament roperties unusual, but not for environment.
- Detection only possible because of fortuitous geometry.



Dietrich et al. 2002



Werner et al. 2008



Dietrich et al. 2012