10 Billion Years of Galaxy Alignments in Clusters

Galaxy Clusters 2017 - Santander

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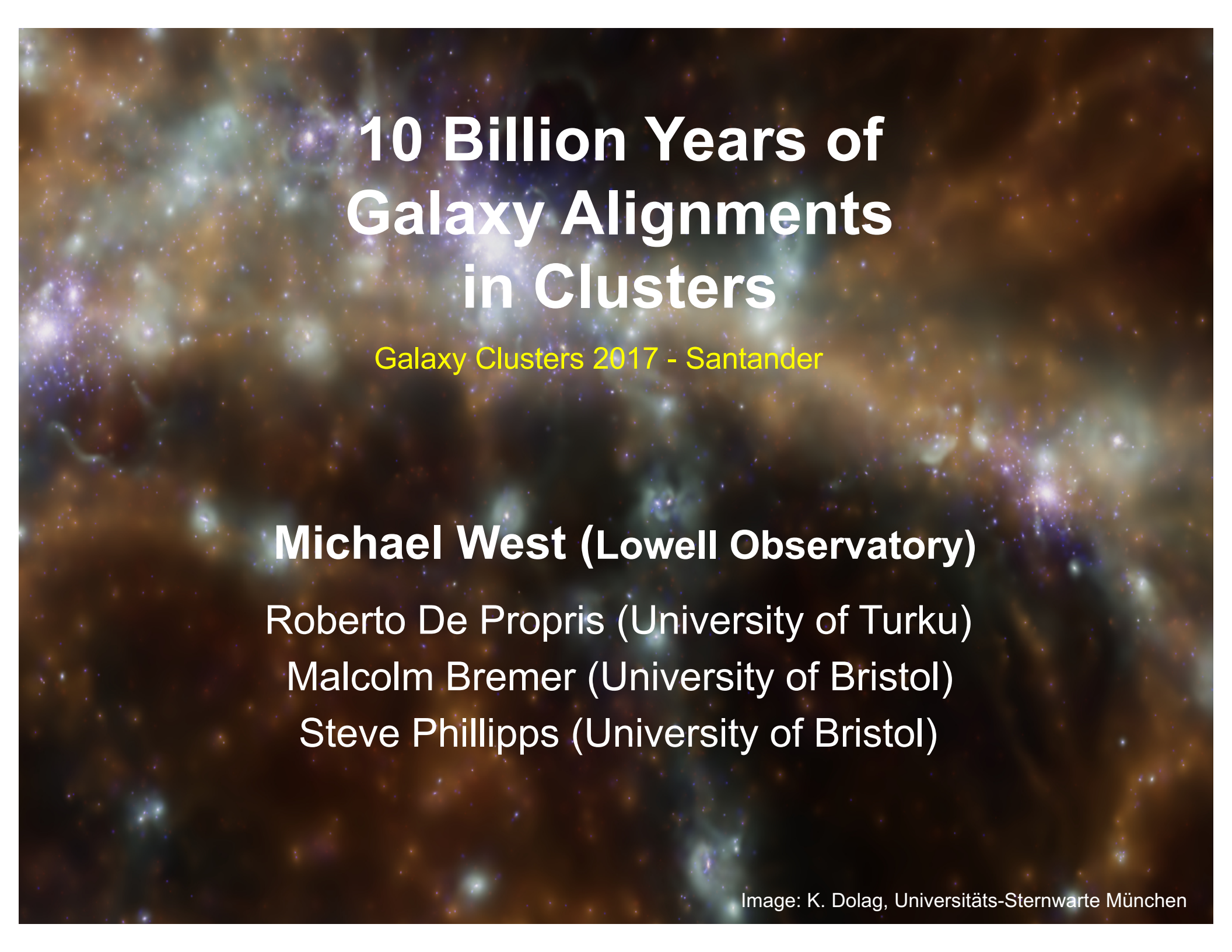
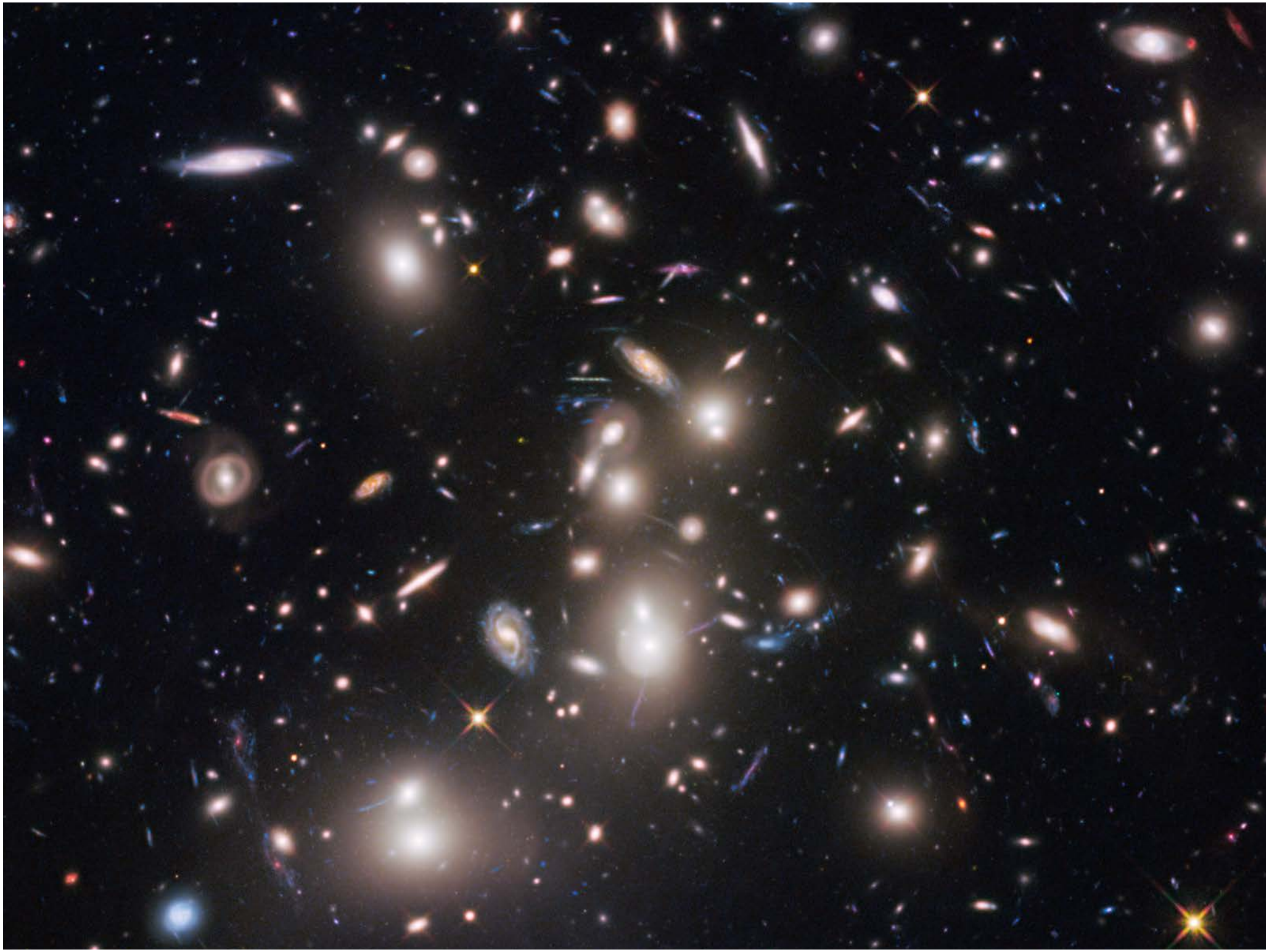


Image: K. Dolag, Universitäts-Sternwarte München



CLUSTERS ASSOCIATED WITH SUPERGIANT GALAXIES

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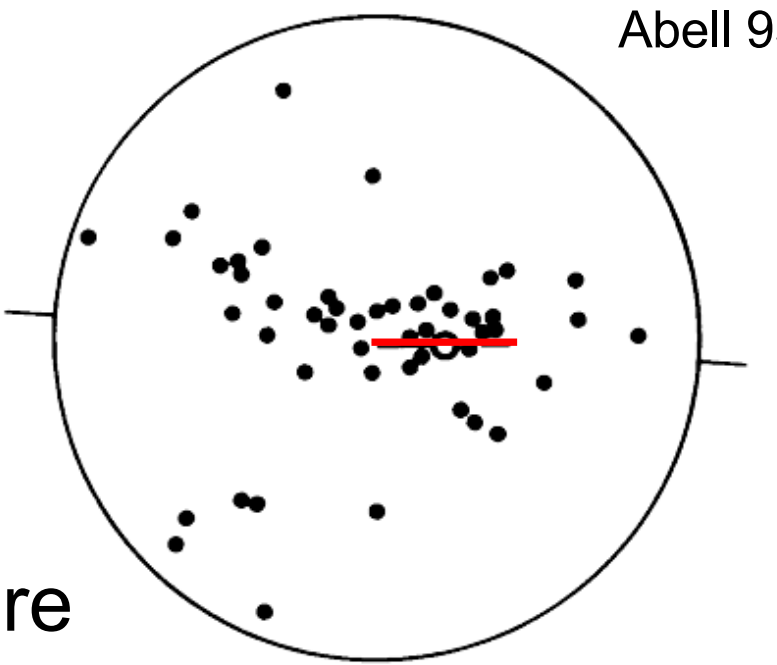
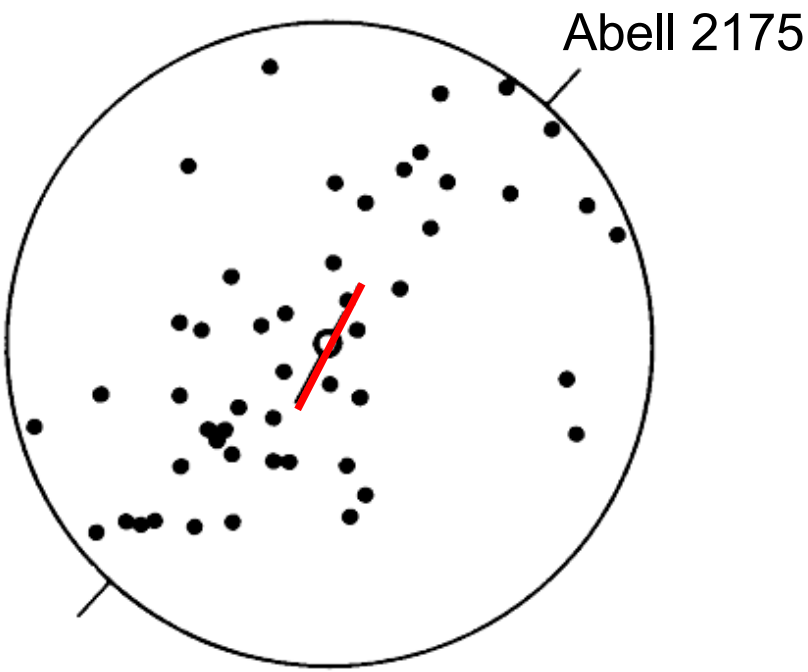
New techniques are developed for a rough but rapid determination of position angle, ellipticity, compactness, and center of distribution of galaxies in a cluster. These methods are applied to clusters associated with supergiant (Morgan cD) galaxies. There is a strong tendency for the major axis of the distribution of galaxies to be oriented along the major axis of the cD galaxy. The relative compactness of brighter and fainter members indicate that the radio cD clusters are dynamically younger than the nonradio cD clusters.

In the last decade Zwicky (1957, 1964) has extensively studied the distribution of galaxies in nearby clusters, such as the Coma and Cancer clusters and the cD cluster around NGC 541, on 18-inch and 48-inch Schmidt telescope plates. Abell (1958) has prepared a catalog of rich clusters using the original Palomar 48-inch Schmidt *Sky Survey* plates. Recently, Noonan (1961) reinterpreted Zwicky's counts of Coma Cluster galaxies to derive the structure of that cluster. This structure was confirmed by means of independent

Brightest cluster galaxies share the same orientations as their host clusters

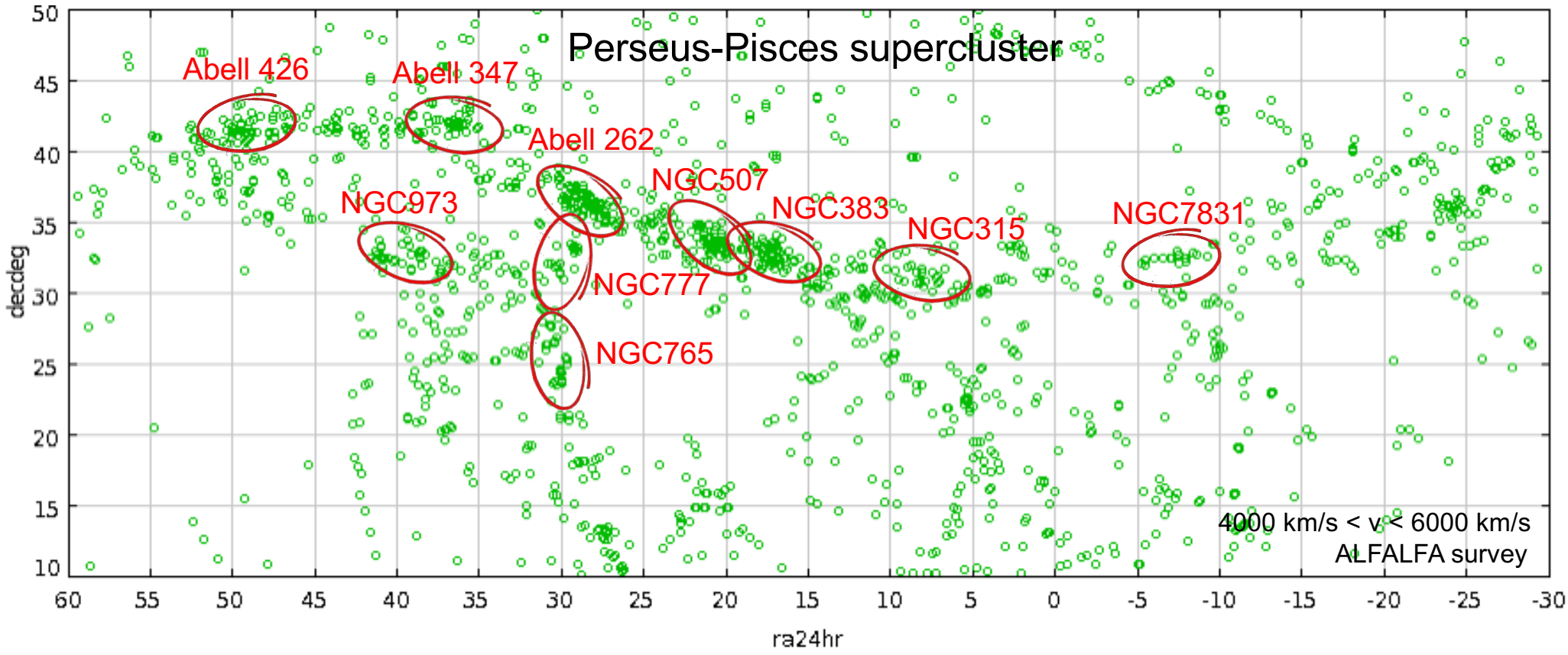




Sastry 1968
Carter & Metcalfe 1980
Binggeli 1982
Lambas, Groth & Peebles 1988
West 1994
Niederste-Ostholt et al. 2010

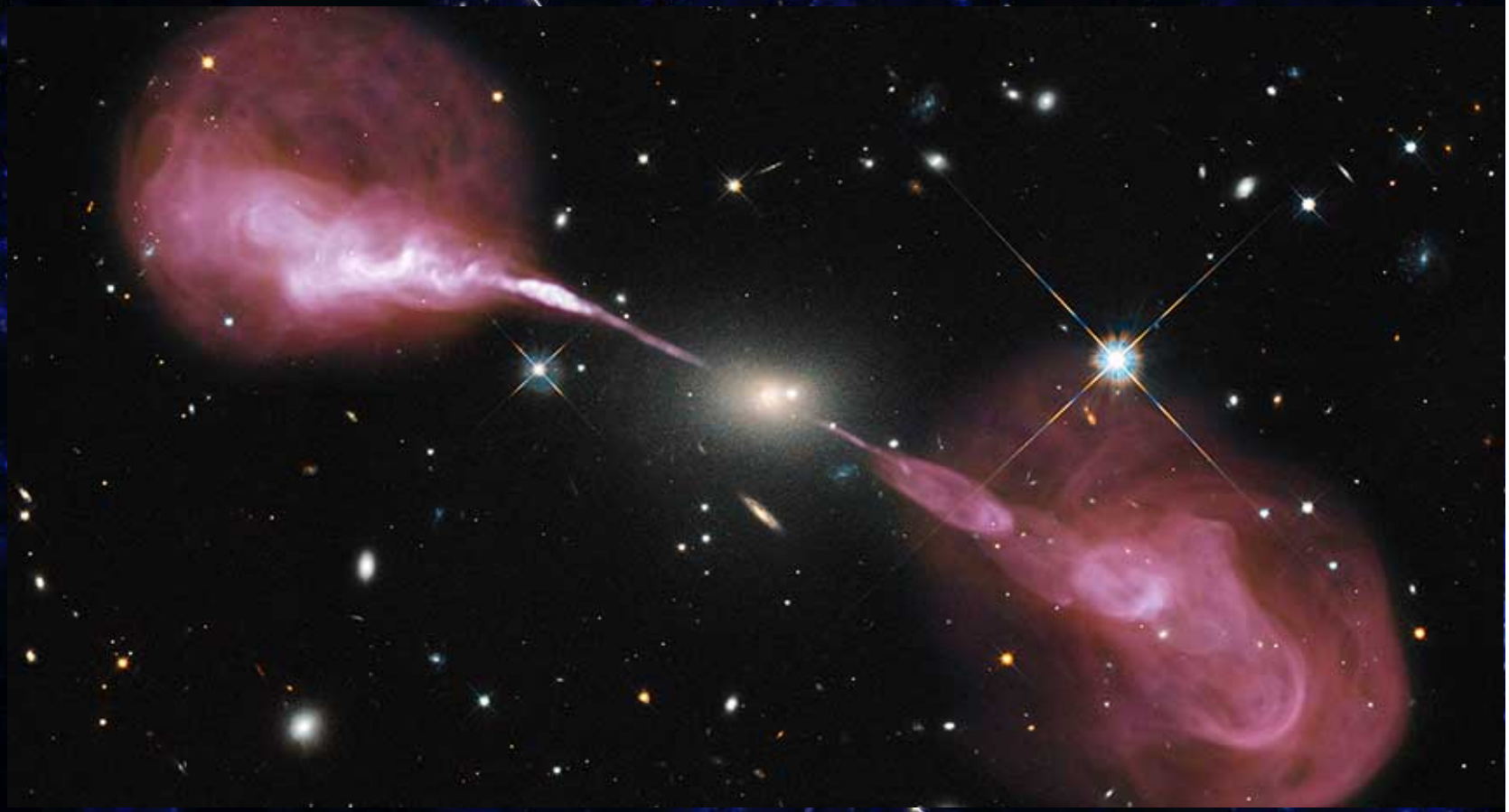
Clusters and groups are aligned over tens of Mpc

"The orientations of clusters in superclusters is a conspicuous morphological property of superclusters." – Einasto et al 1980



Binggeli 1982
Plionis 1994
West, Jones & Forman 1995
Paz et al. 2011
Smargon et al. 2012
Huang et al. 2016

Alignment of quasar black hole spin axes over large scales



West 1994
Hutsemékers et al. 2014
Pelgrims & Hutsemékers 2016

Image: ESO/M. Kornmesser

Why do galaxy alignments matter?

They provide clues about the role of large-scale environment in galaxy formation and evolution

Intrinsic alignments are a source of contamination for weak-lensing measurements

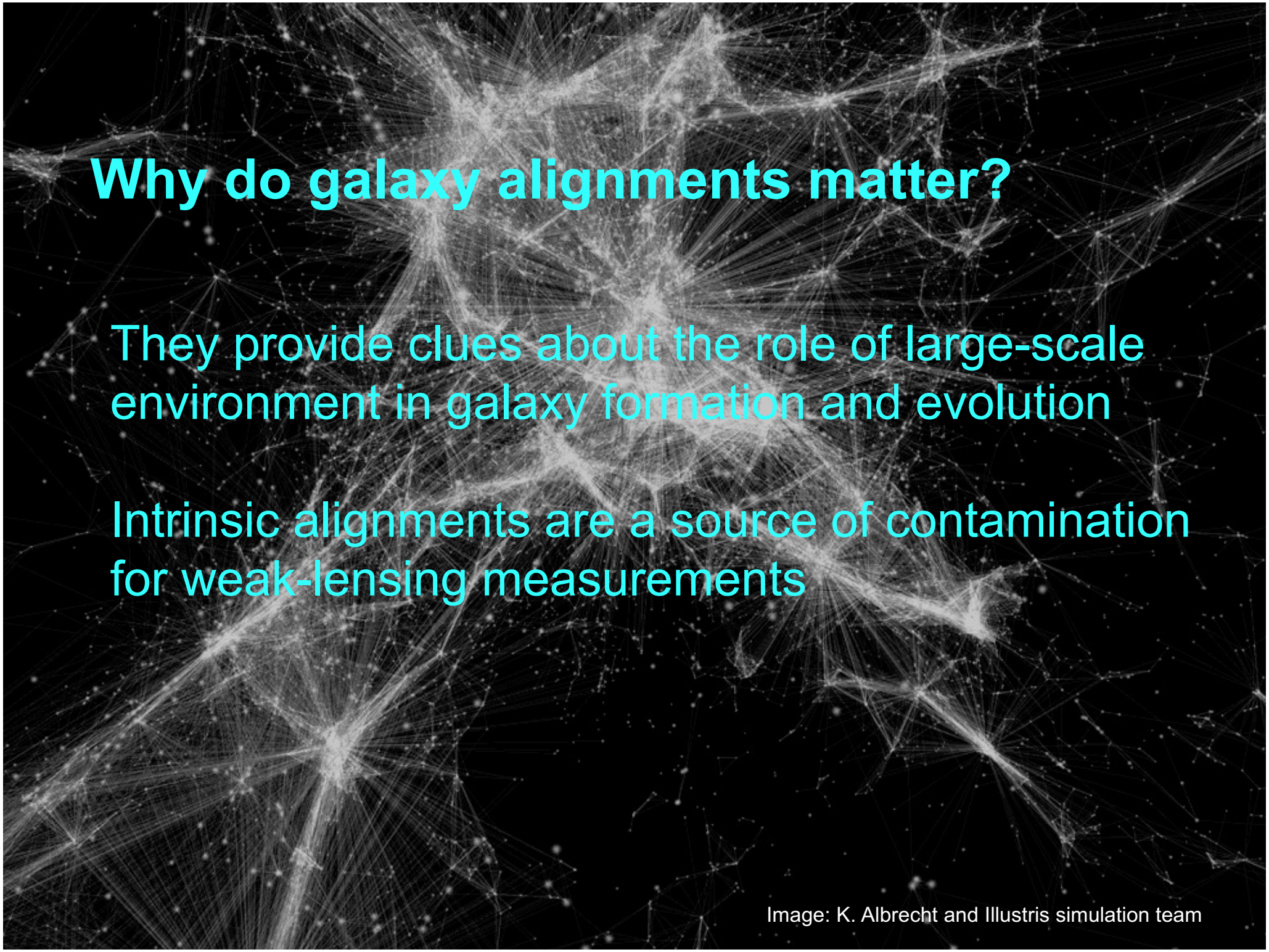
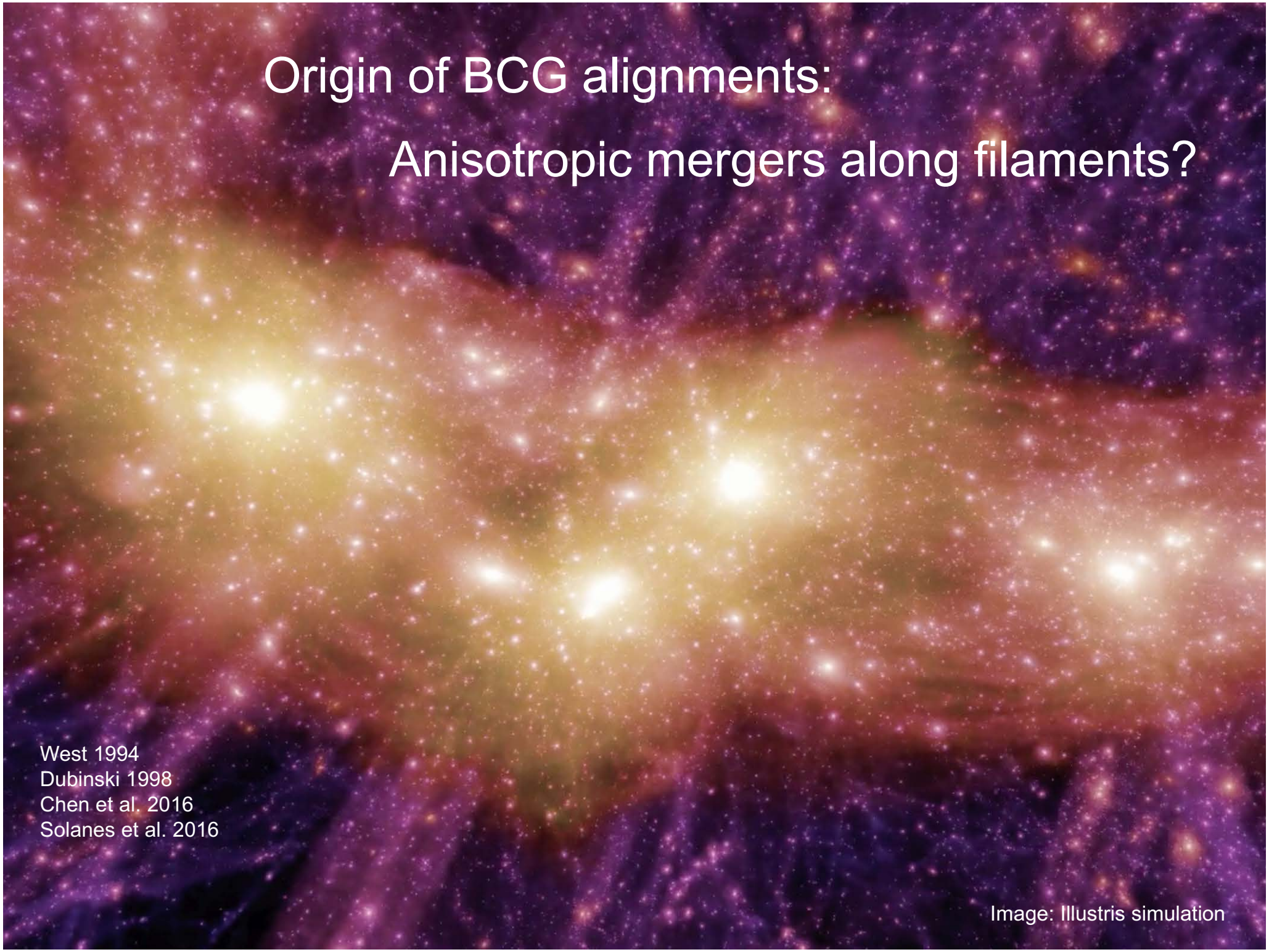
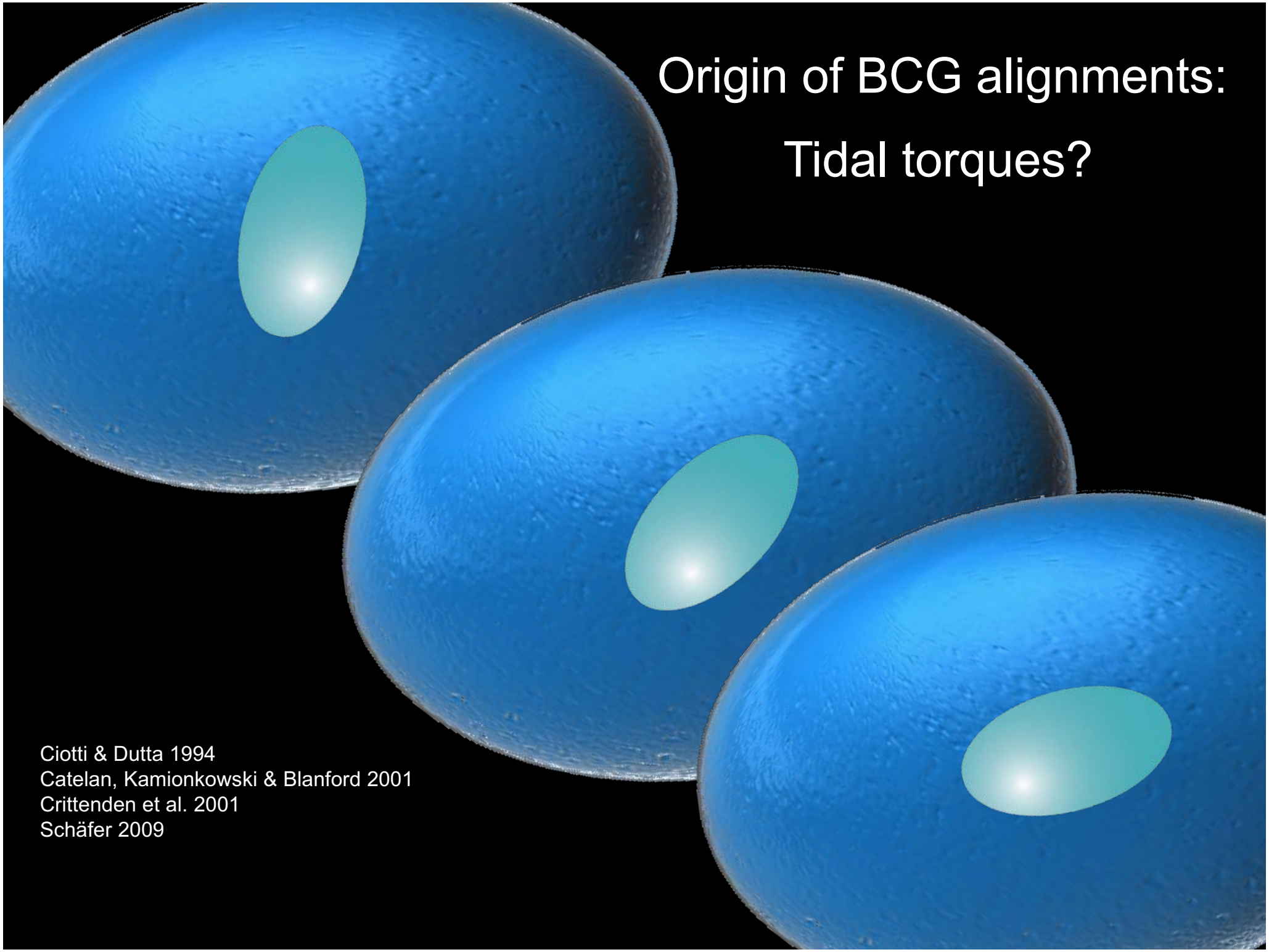
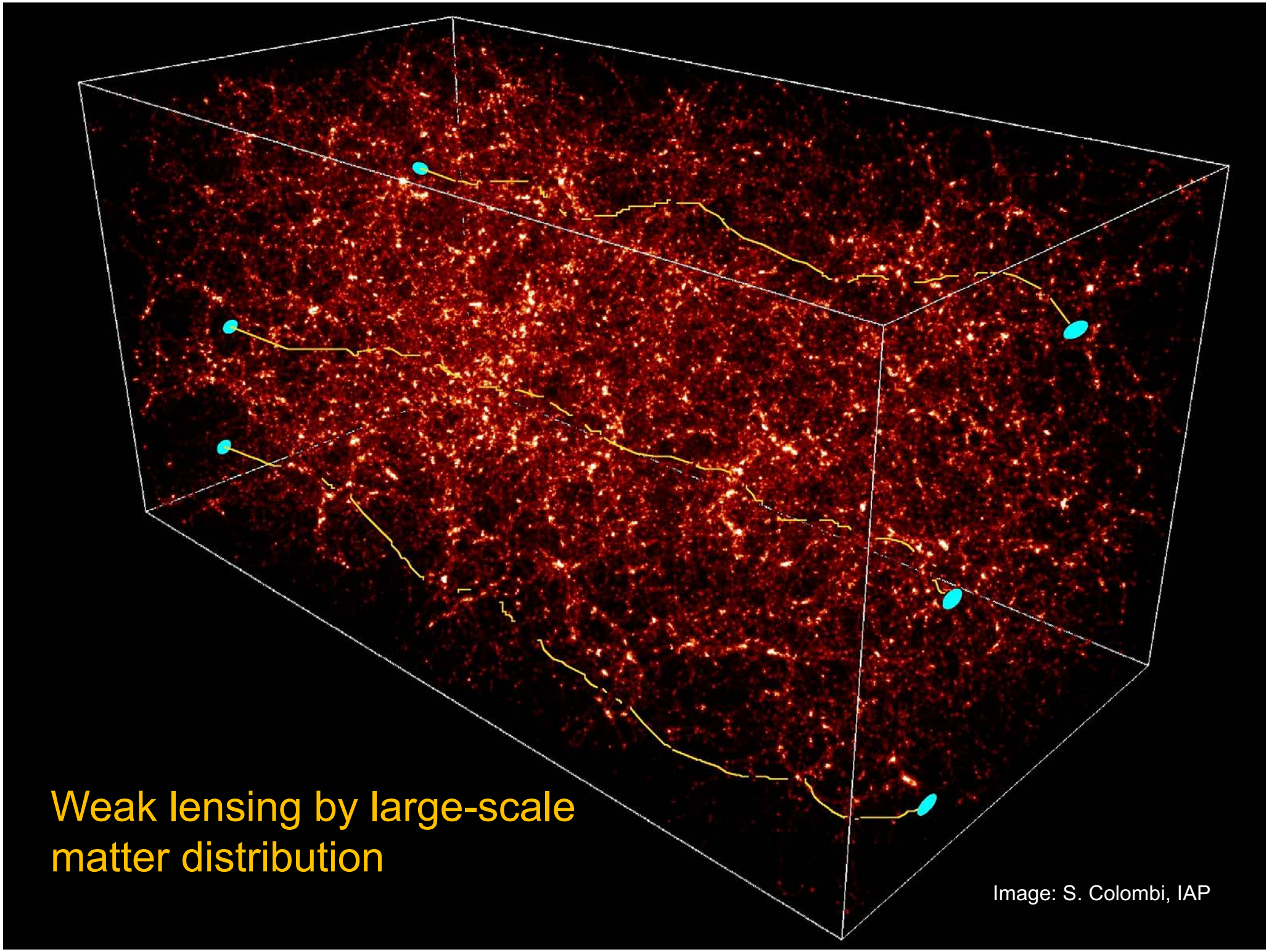
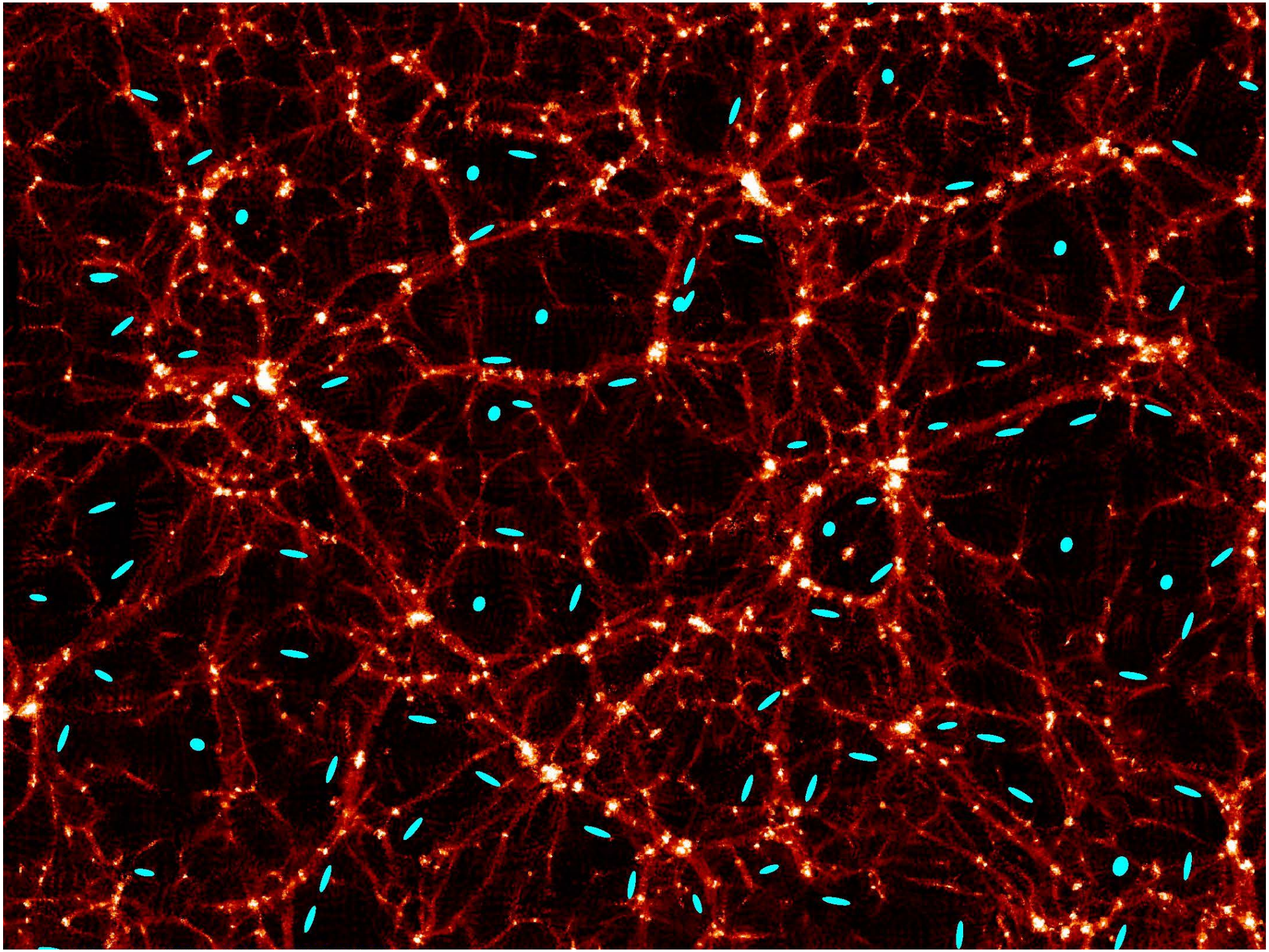


Image: K. Albrecht and Illustris simulation team

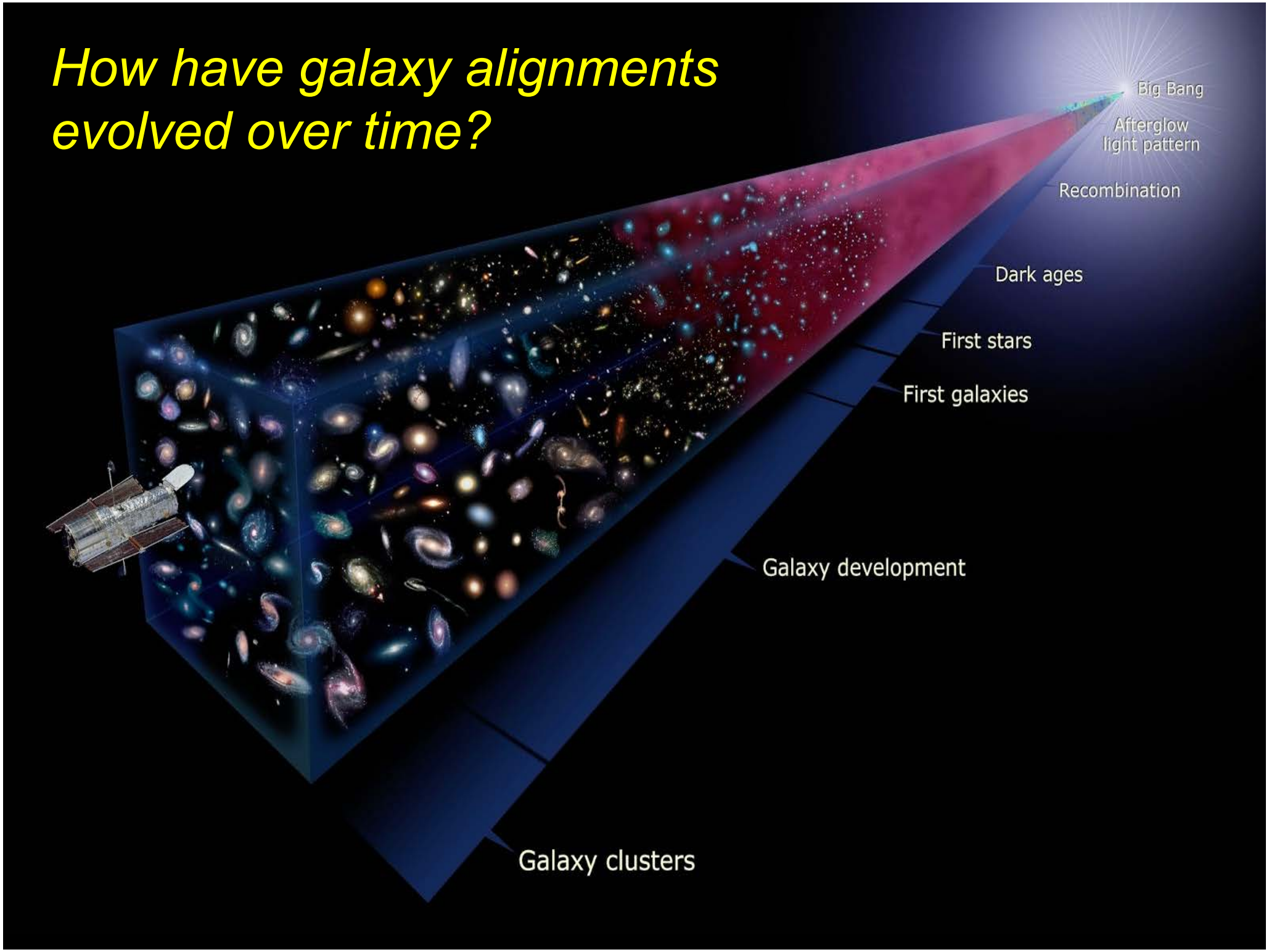

Origin of BCG alignments:
Anisotropic mergers along filaments?
West 1994
Dubinski 1998
Chen et al. 2016
Solanes et al. 2016
Image: Illustris simulation

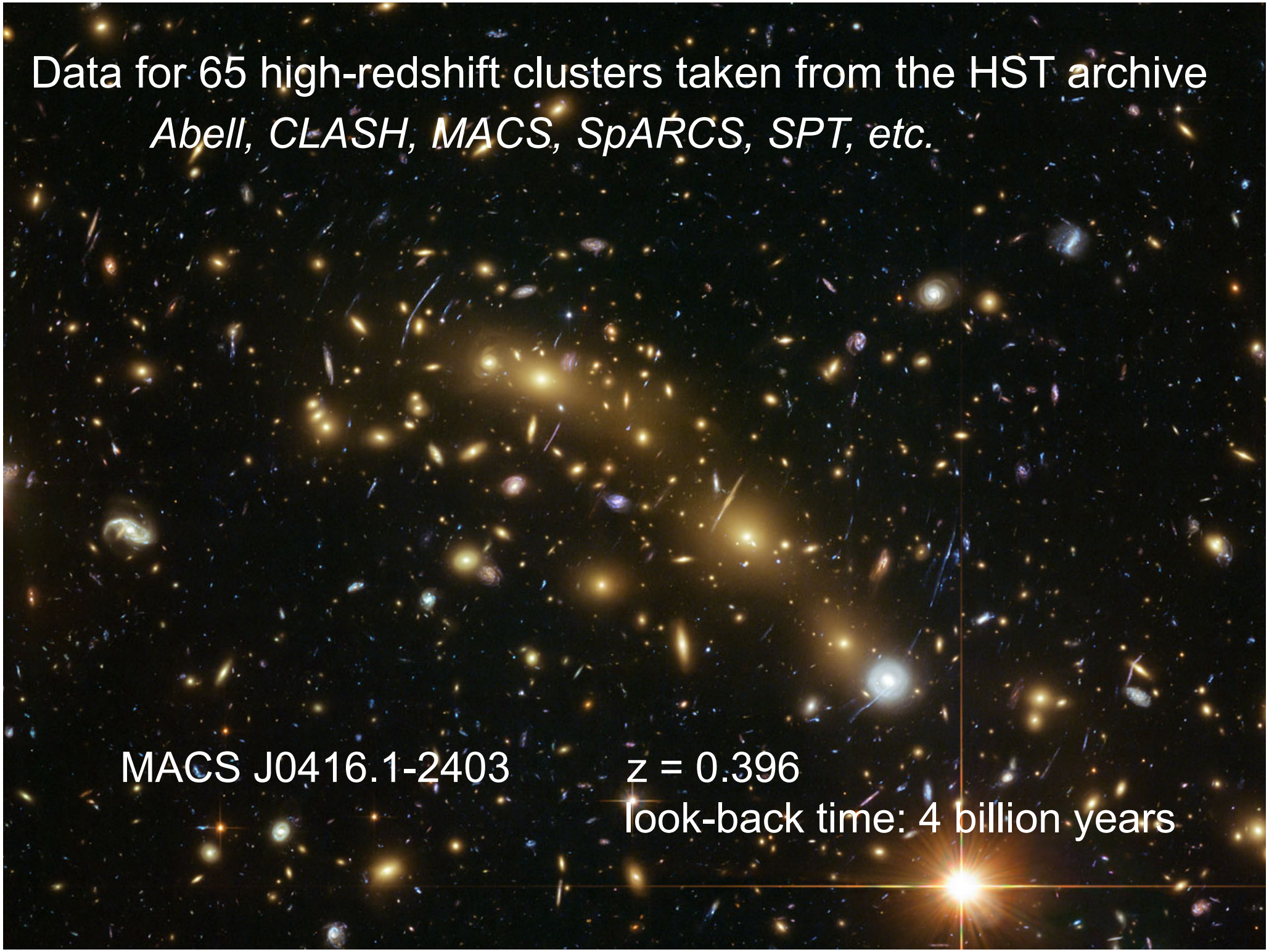

Origin of BCG alignments:
Tidal torques?
Ciotti & Dutta 1994
Catelan, Kamionkowski & Blanford 2001
Crittenden et al. 2001
Schäfer 2009

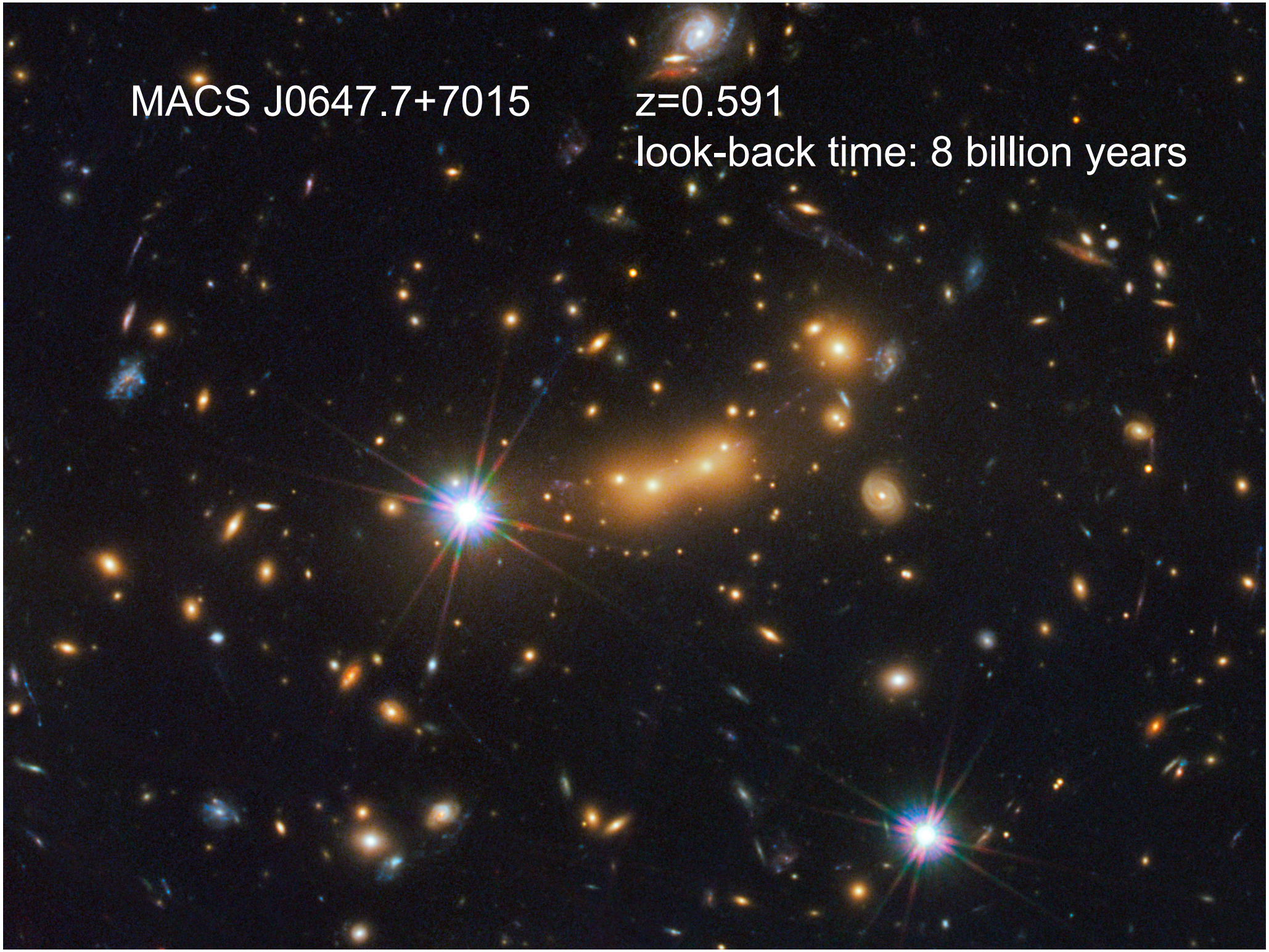

Weak lensing by large-scale
matter distribution
Image: S. Colombi, IAP

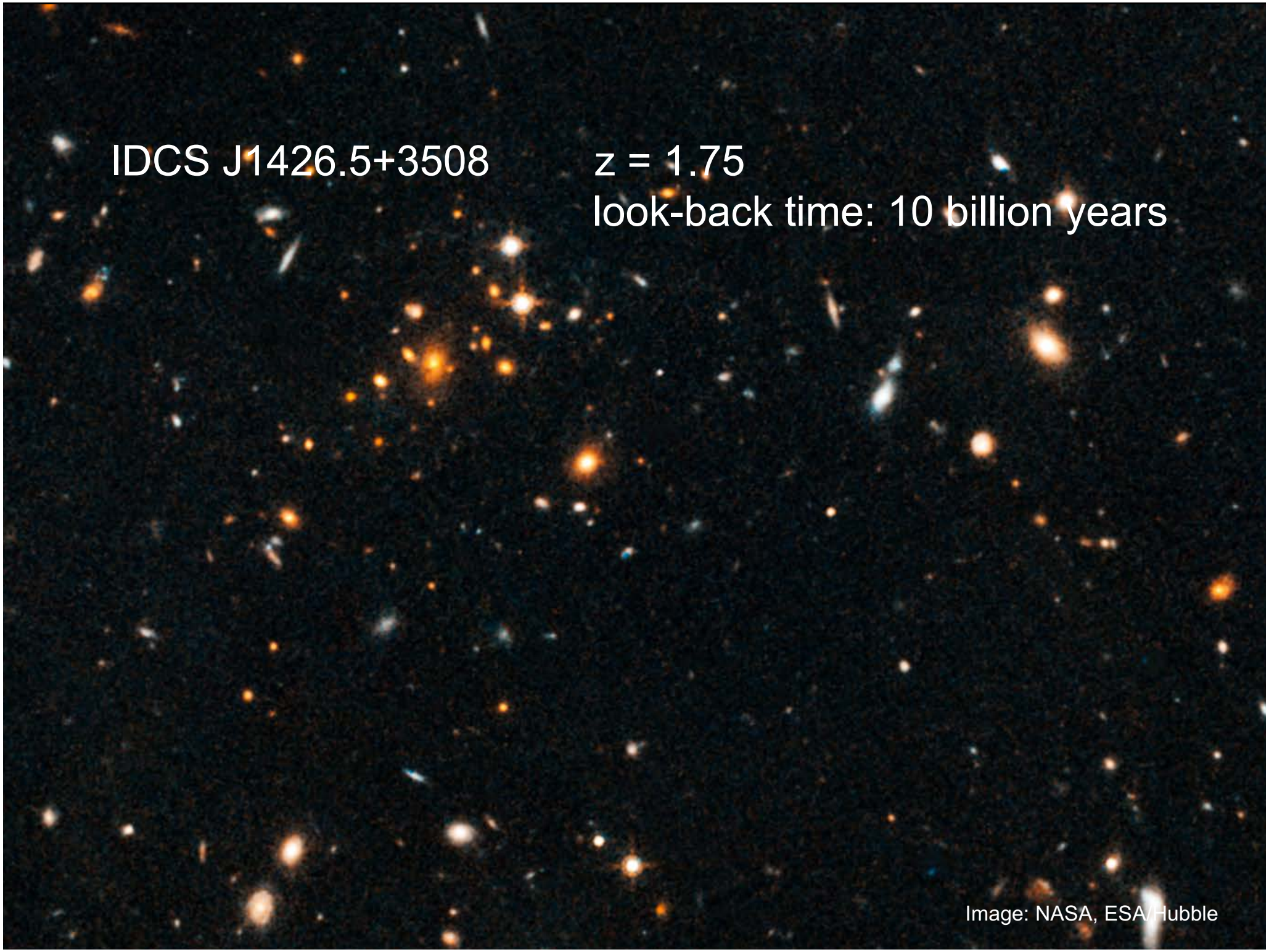


How have galaxy alignments evolved over time?

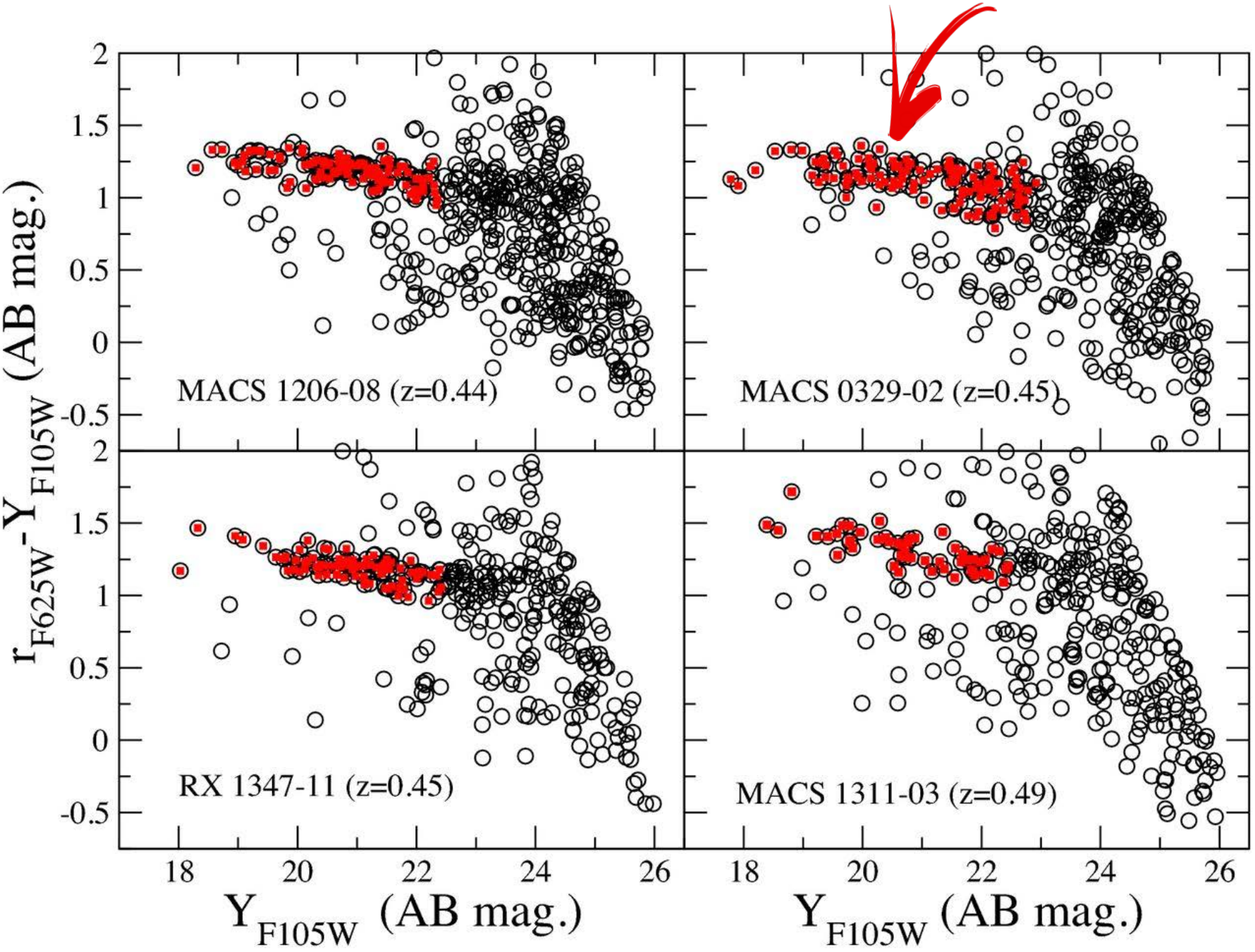


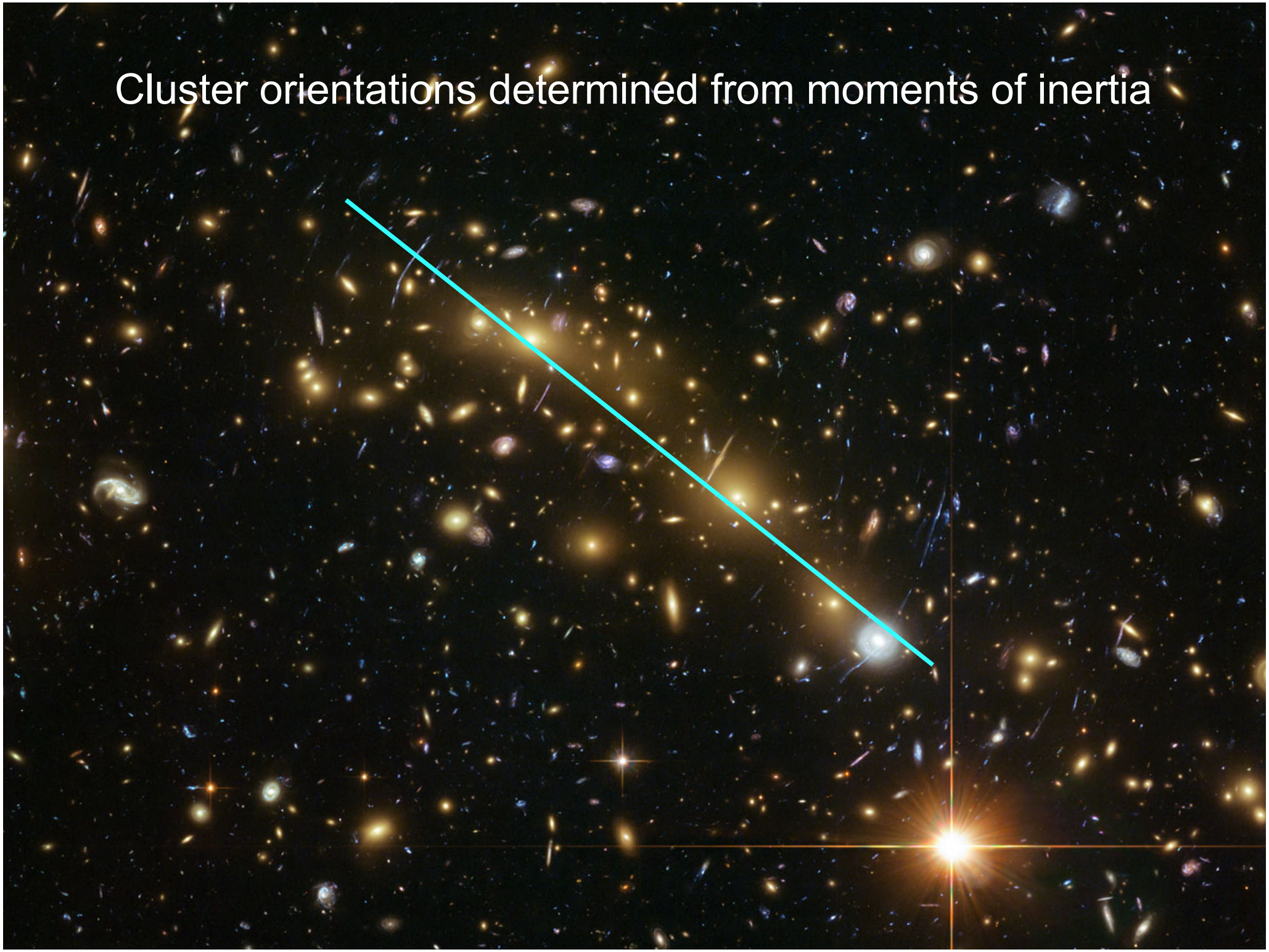

Data for 65 high-redshift clusters taken from the HST archive
Abell, CLASH, MACS, SpARCS, SPT, etc.
MACS J0416.1-2403
z = 0.396
look-back time: 4 billion years

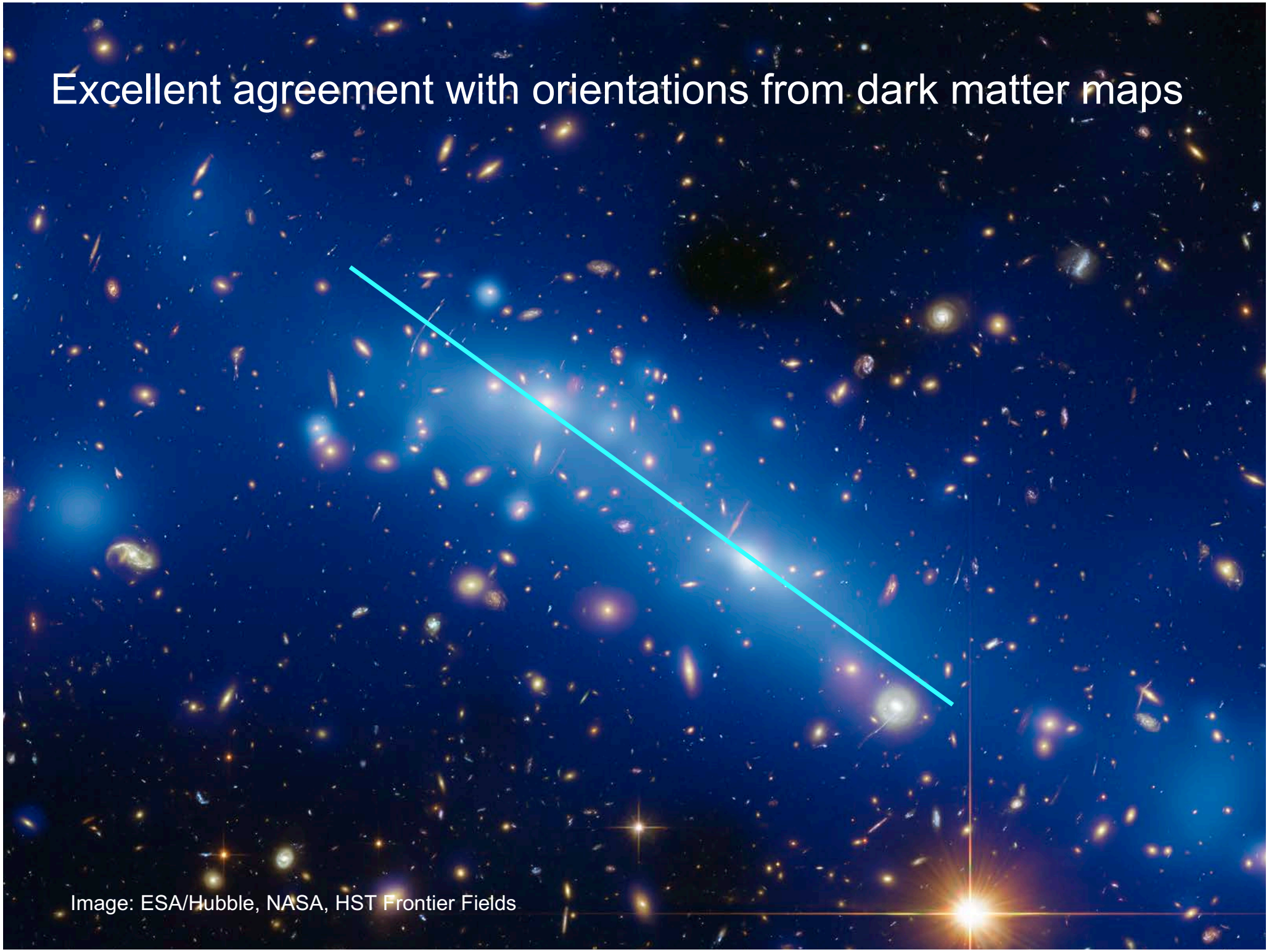

MACS J0647.7+7015
z=0.591
look-back time: 8 billion years

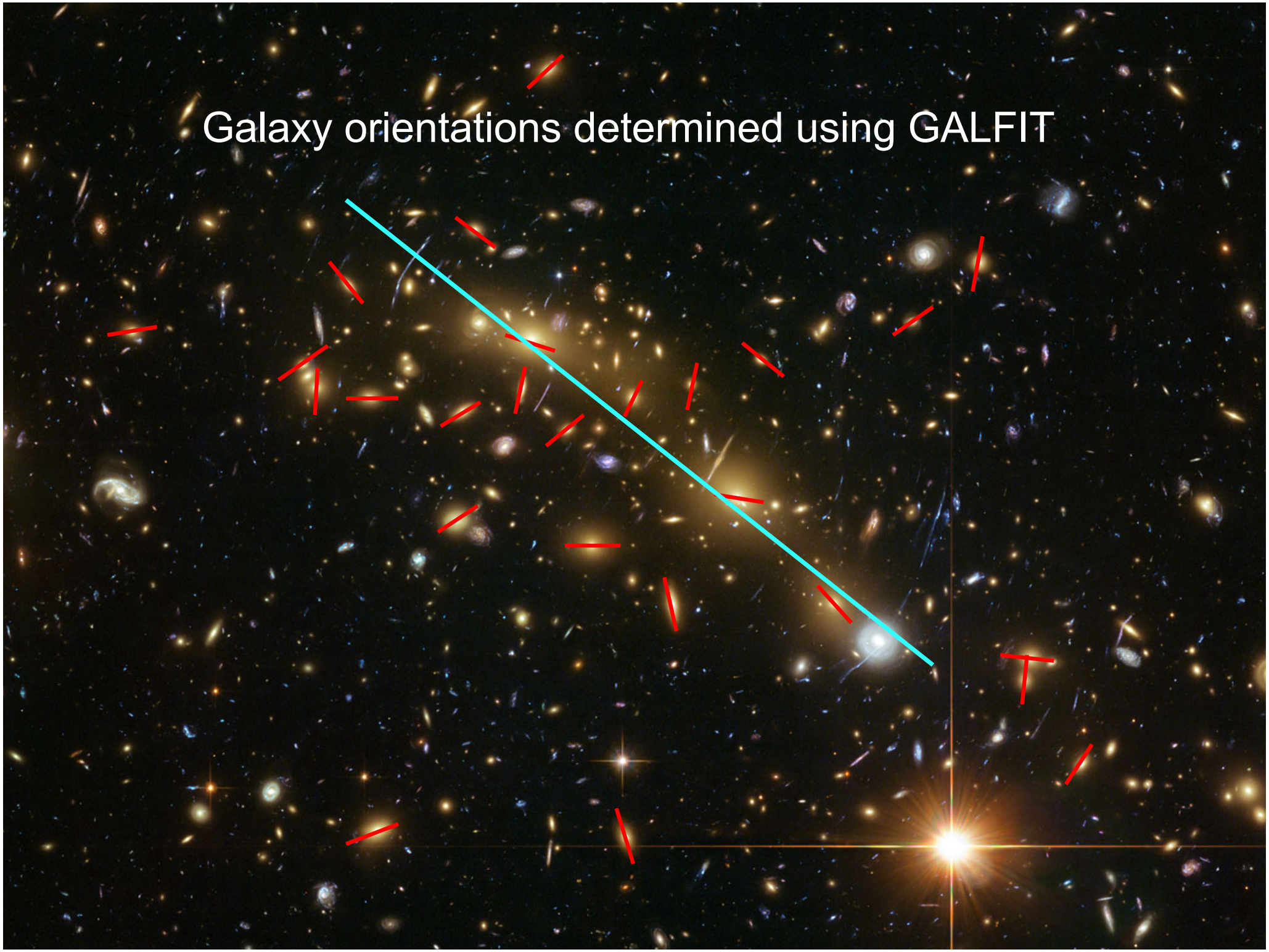

IDCS J1426.5+3508
z = 1.75
look-back time: 10 billion years
Image: NASA, ESA/Hubble

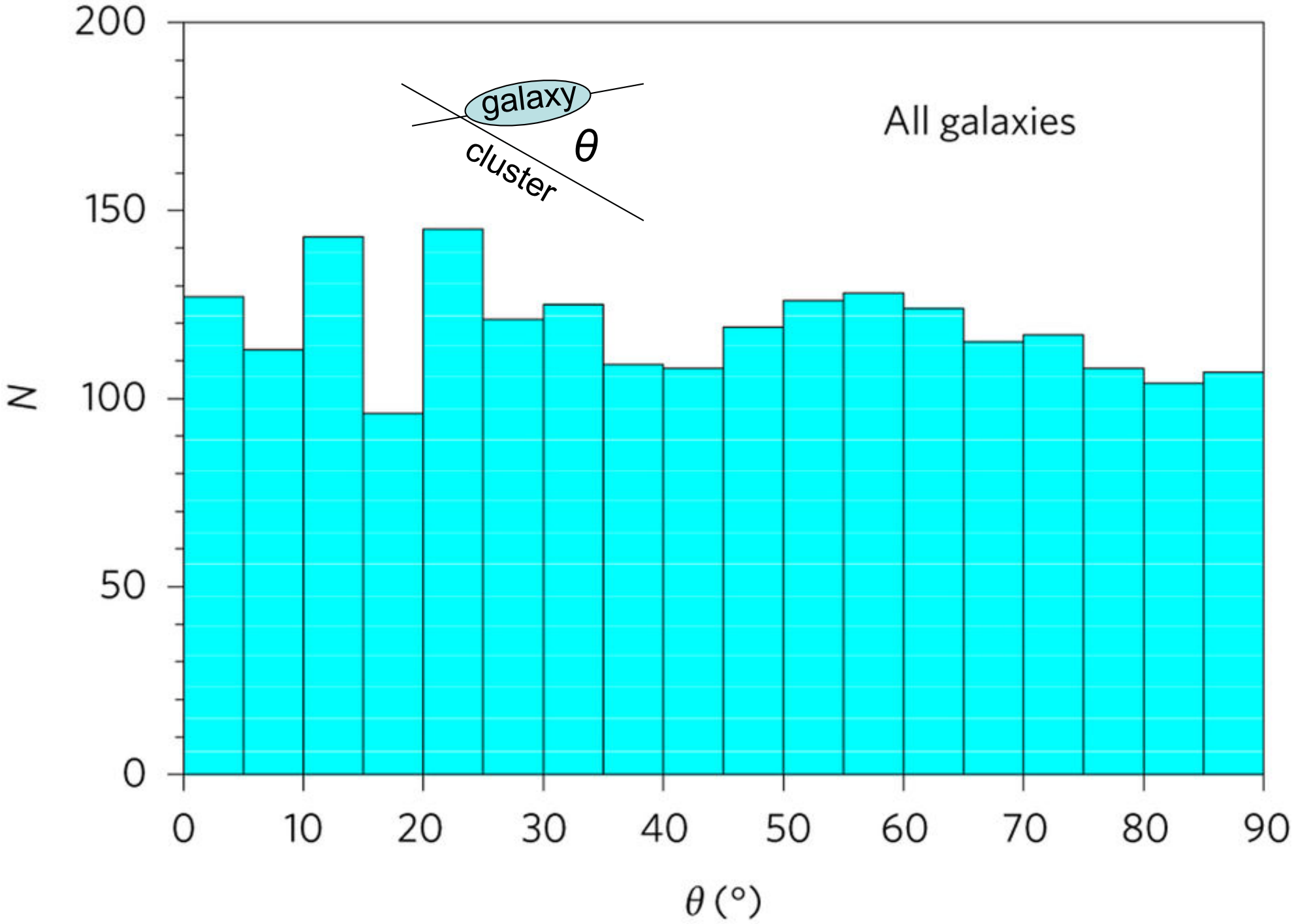
Cluster members identified from the red sequence

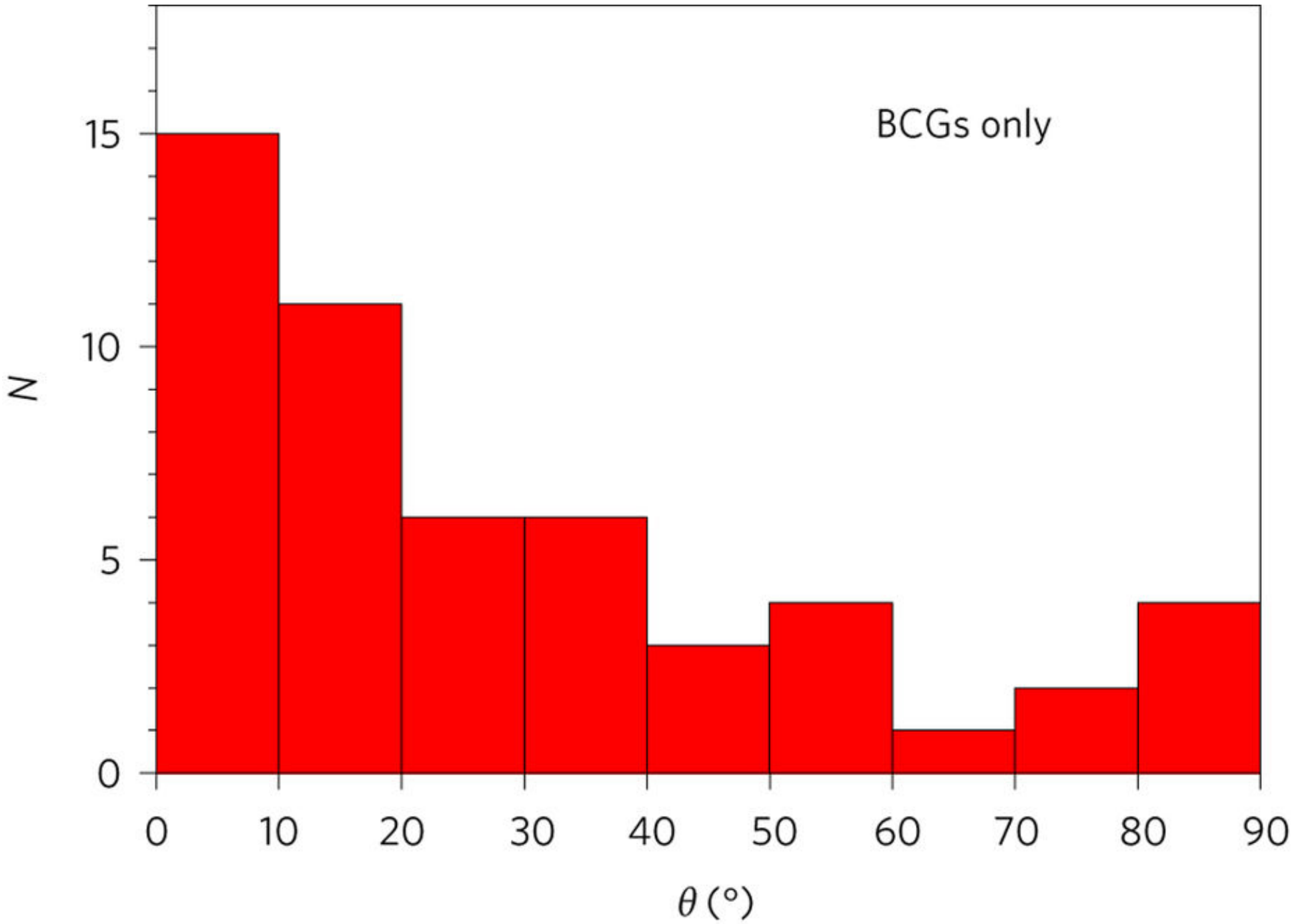


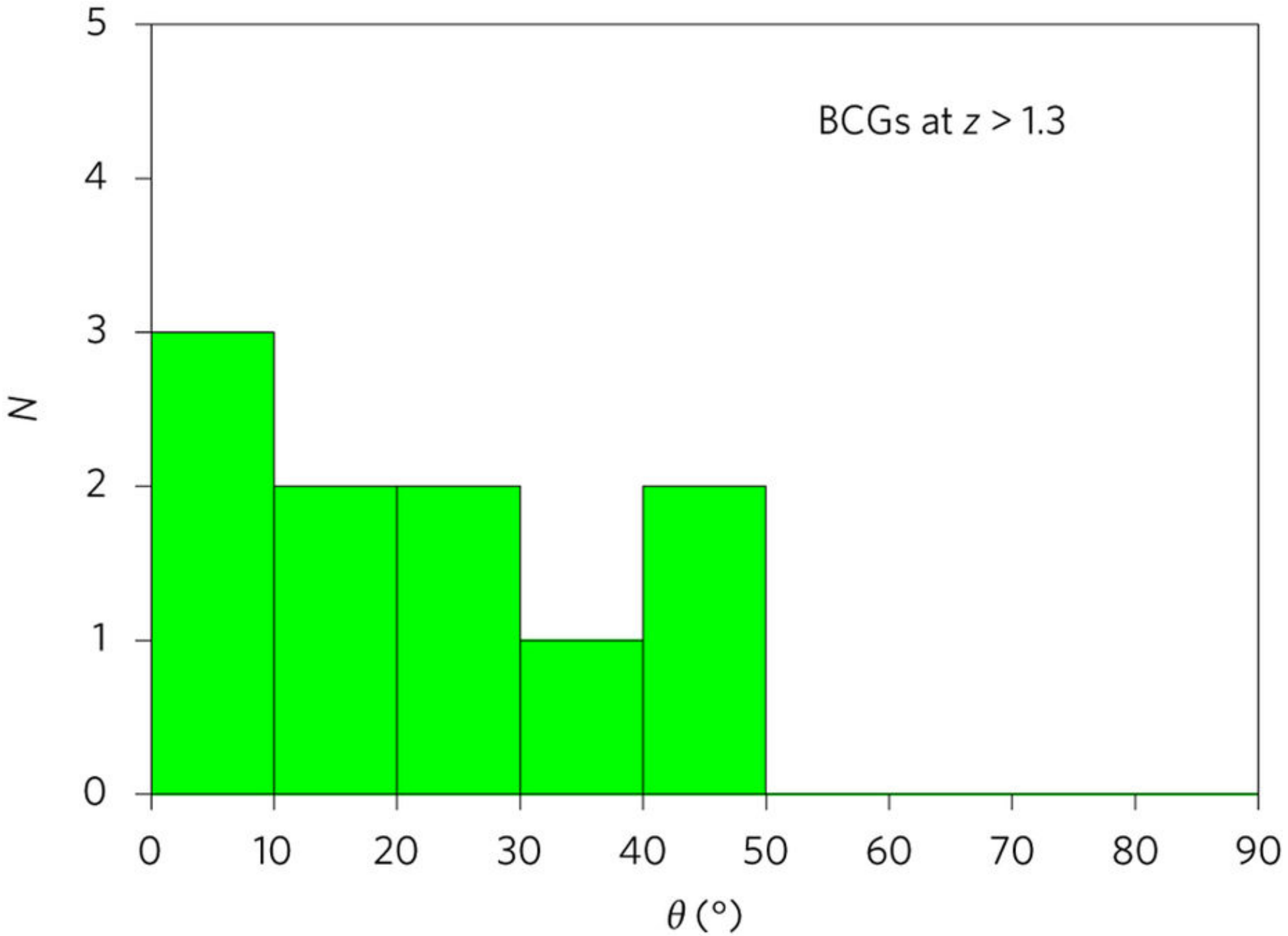

Cluster orientations determined from moments of inertia

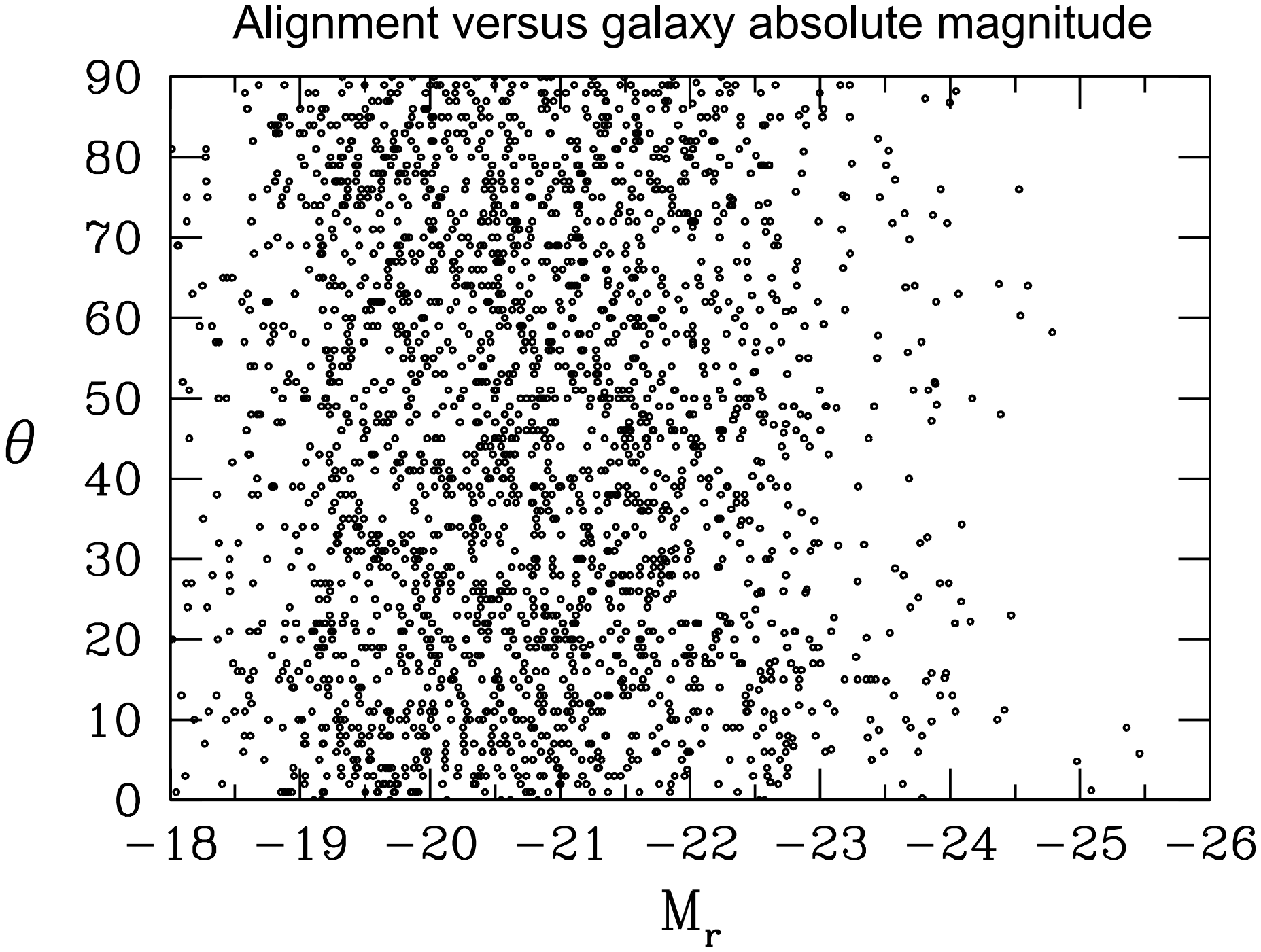

Excellent agreement with orientations from dark matter maps
Image: ESA/Hubble, NASA, HST Frontier Fields

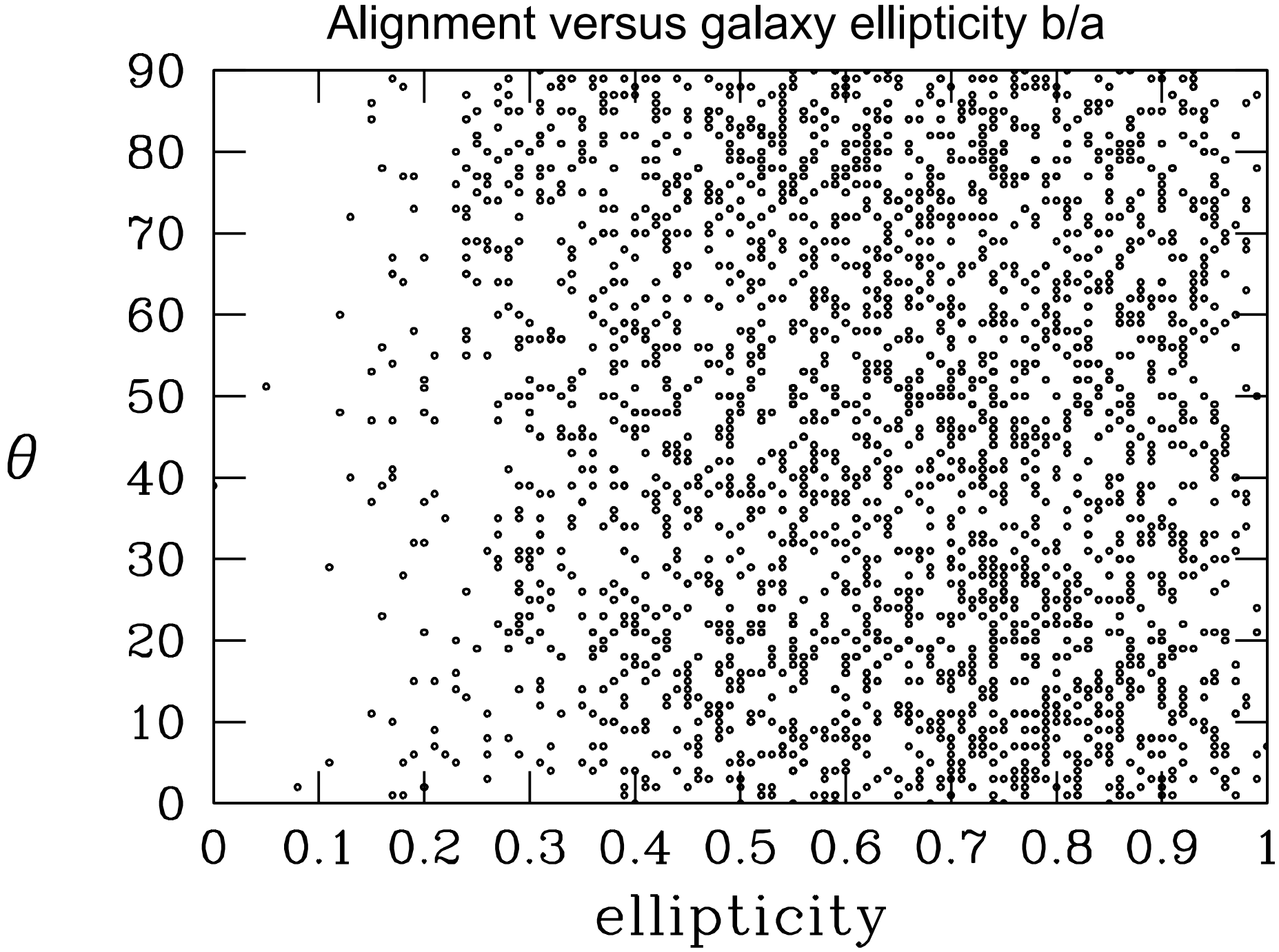

Galaxy orientations determined using GALFIT

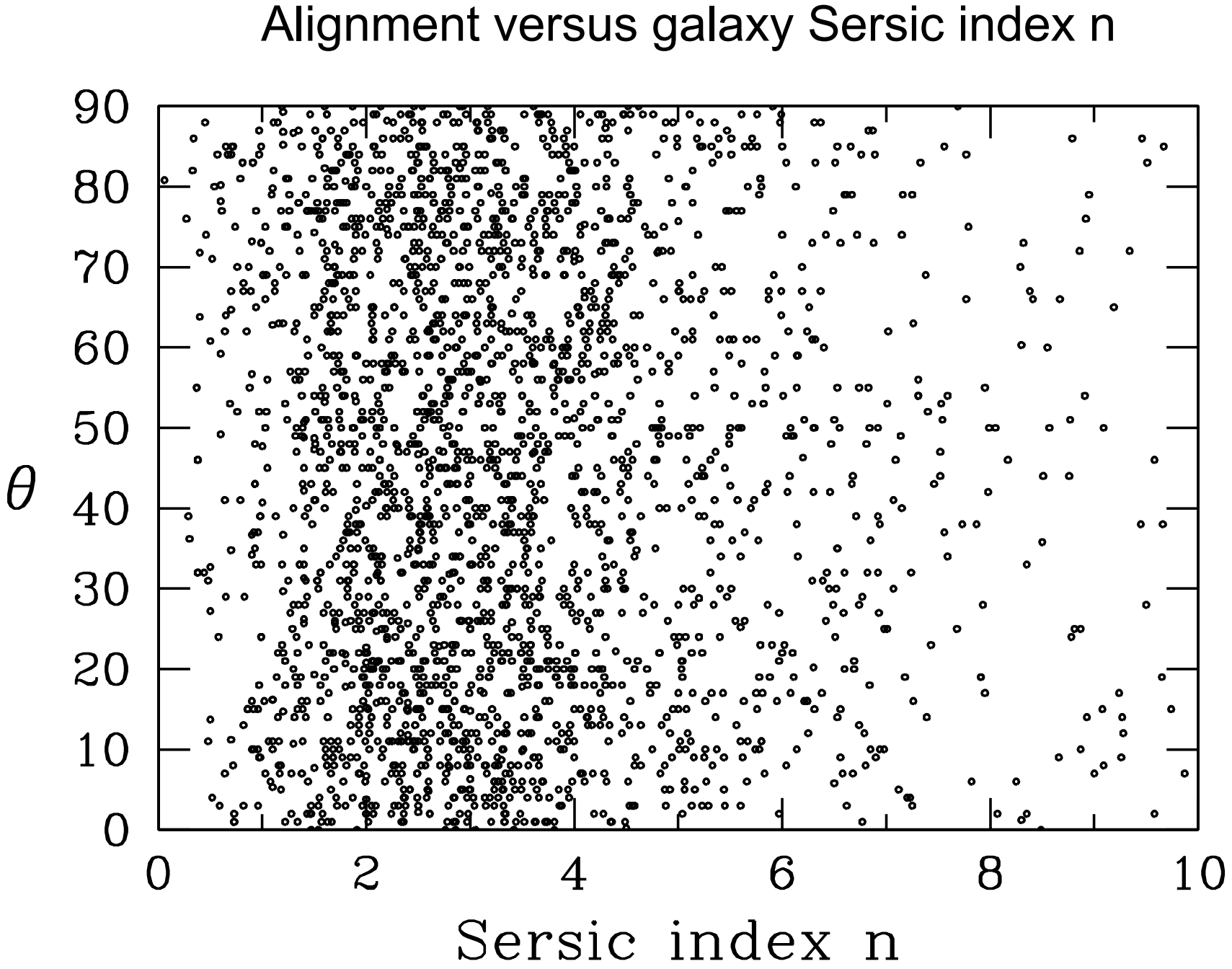

200
150
100
50
0
N
0
10
20
30
40
50
60
70
80
90
θ (°)
galaxy
cluster
θ
All galaxies


BCGs only
15
10
5
0
N
0
10
20
30
40
50
60
70
80
90
θ (°)


BCGs at $z > 1.3$
N
θ (°)
0
1
2
3
4
5
0
10
20
30
40
50
60
70
80
90


Alignment versus galaxy absolute magnitude
90
80
70
60
50
40
30
20
10
0
θ
−18
−19
−20
−21
−22
−23
−24
−25
−26
M_r


Alignment versus galaxy ellipticity b/a
90
80
70
60
50
40
30
20
10
0
θ
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
ellipticity


Alignment versus galaxy Sersic index n
θ
90
80
70
60
50
40
30
20
10
0
0
2
4
6
8
10
Sersic index n

nature astronomy

LETTERS

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Ten billion years of brightest cluster galaxy alignments

Michael J. West[1]*, Roberto De Propris[2], Malcolm N. Bremer[3] and Steven Phillipps[3]

A galaxy's orientation is one of its most basic observable properties. Astronomers once assumed that galaxies are randomly oriented in space; however, it is now clear that some have preferred orientations with respect to their surroundings. Chief among these are giant elliptical galaxies found in the centres of rich galaxy clusters. Numerous studies have shown that the major axes of these galaxies often share the same orientation as the surrounding matter distribution on larger scales[1-6]. Using Hubble Space Telescope observations of 65 distant galaxy clusters, we show that similar alignments are seen at earlier epochs when the Universe was only one-third of its current age. These results suggest that the brightest galaxies in clusters are the product of a special formation history, one influenced by development of the cosmic web over billions of years.

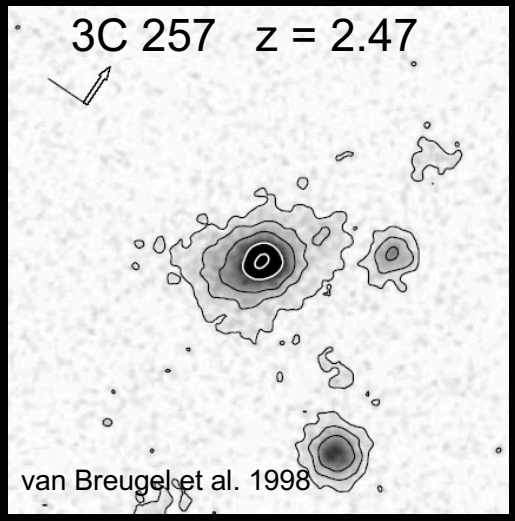
The most massive galaxies in the Universe appear to know about their surroundings. It is well established that the major axes of brightest cluster galaxies (BCGs) are often elongated in the same

The orientation of each cluster's principal axis was determined by computing the moments of inertia of the distribution of red-sequence galaxies (see Methods), which are reliable tracers of the cluster mass distribution[17]. Cluster position angles are given in Supplementary Table 1, along with 1σ uncertainties derived from bootstrap resampling, which are typically 10–20°. Thirteen clusters with position angles uncertain by >25° were culled from the sample, leaving 52 clusters for subsequent analysis. Cluster orientations obtained from moments of inertia were in good agreement with other independent determinations[18]. As a further check, for the clusters in the Cluster Lensing And Supernova survey with Hubble (CLASH)[12] sample with published mass models derived from gravitational lensing analysis, we measured each cluster's principal axis and its orientation by fitting ellipses to the inferred mass distribution. The agreement is excellent in general, with a median difference of only 11° between the position angles obtained from moments of inertia versus gravitational lensing (see Methods).

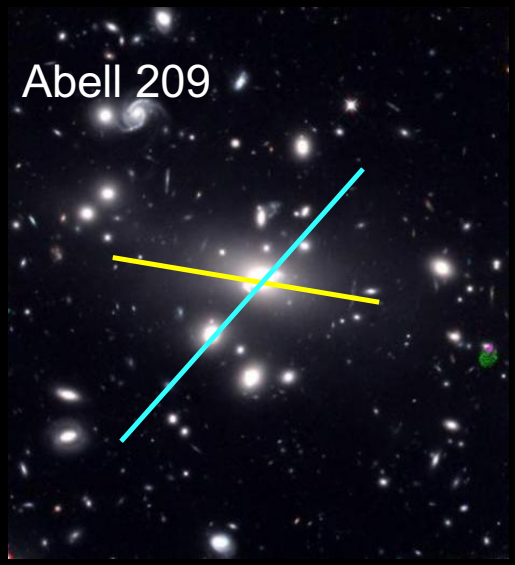
We first examine the general tendency for cluster galaxies of all

What's next?

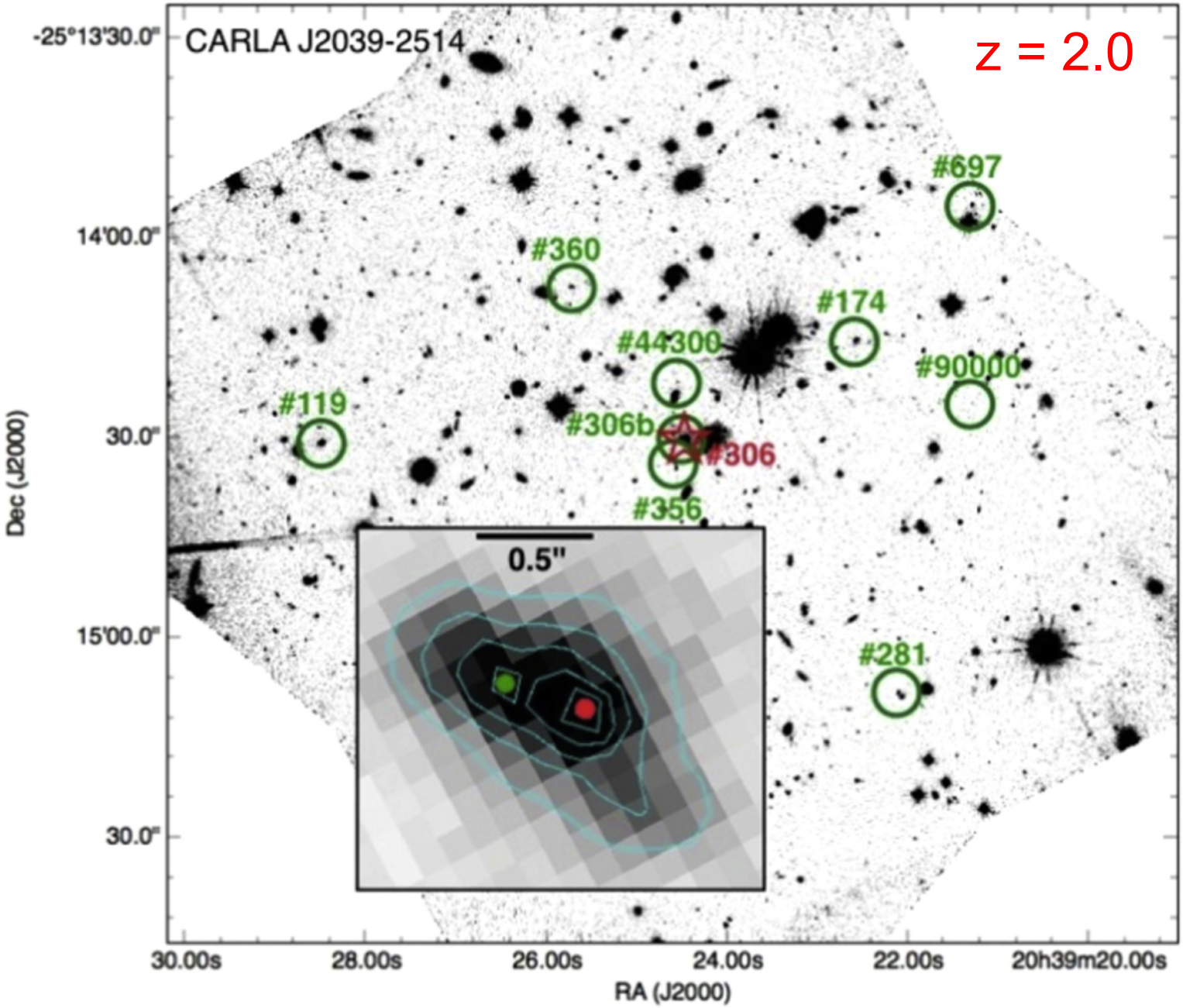
- Larger sample, higher redshifts



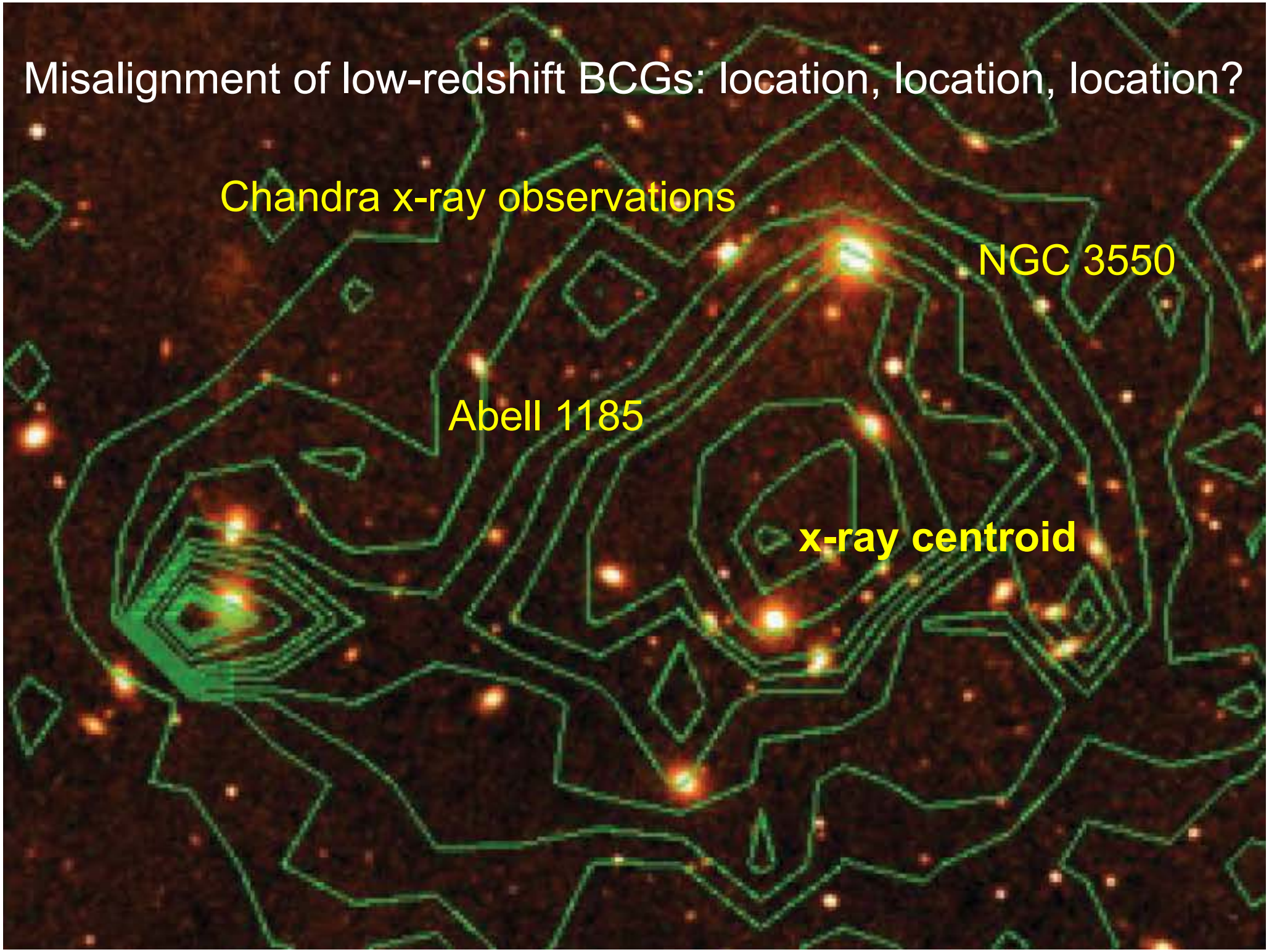
- Why are some BCGs NOT aligned?



Finding the highest redshift BCGs…

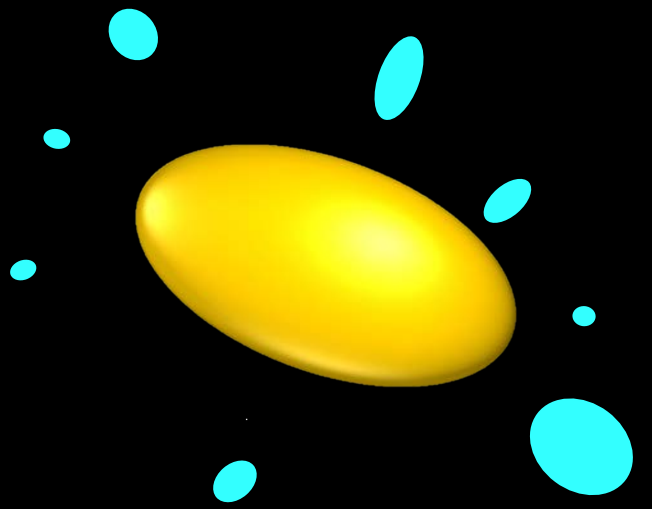


Noirot et al. 2016

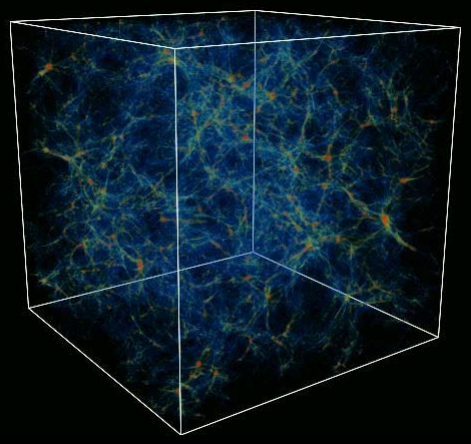

Misalignment of low-redshift BCGs: location, location, location?
Chandra x-ray observations
NGC 3550
Abell 1185
x-ray centroid

What's next?

- Other types of alignments



- Numerical simulations of BCG formation



Conclusions

- Brightest cluster galaxies have been aligned with their host clusters for at least 10 billion years
- They’re the product of a special formation history influenced by development of the cosmic web