Towards an understanding of galaxy clusters

ITP Cosmology Colloquium

Heidelberg, Oct. 26 2011

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Outline

- Clusters of galaxies in the context of structure formation

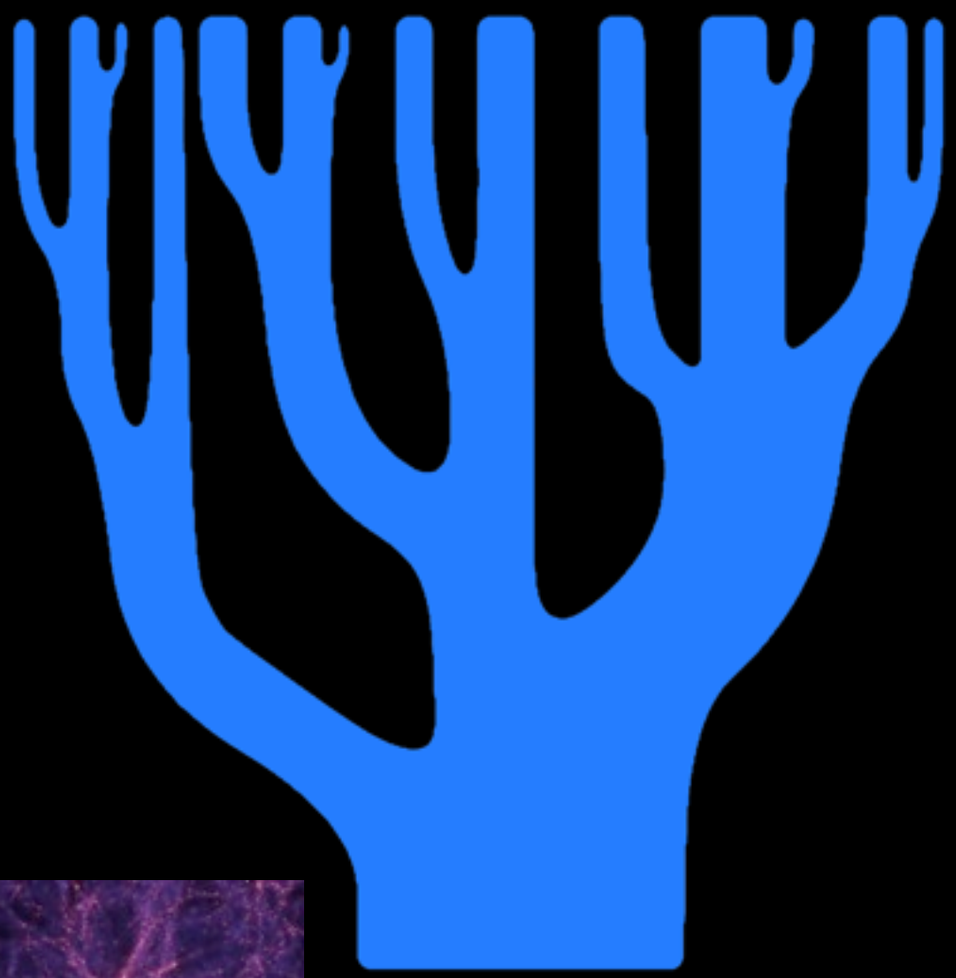
  - Reconstructing mass distributions, as good as possible, as fast as possible

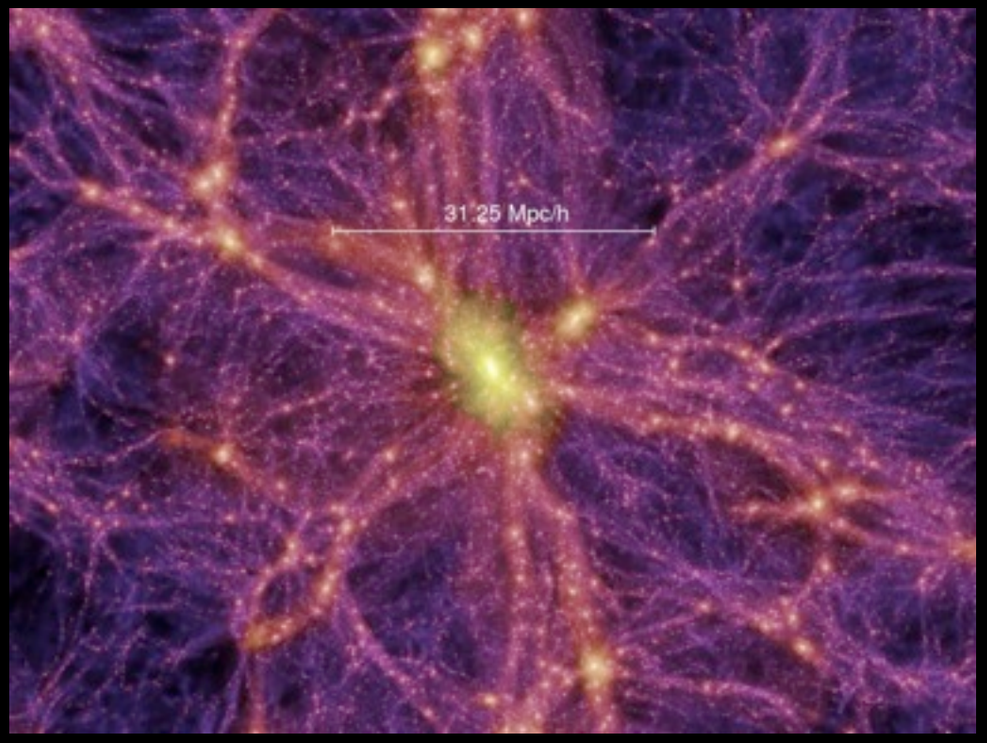
- Two applications: Pandora's cluster meets the CLASH

  - Sensible comparisons to simulations

Structure forms hierarchically

time





Clusters of galaxies

$\sim 10^{15} M_\odot$ & Mpc scales

Appear to be DM dominated
(85% DM, 13% hot gas, 2% stars)

Baryonic component **not**
dominant, though not negligible

All main components are
observable in three wavelength
regimes

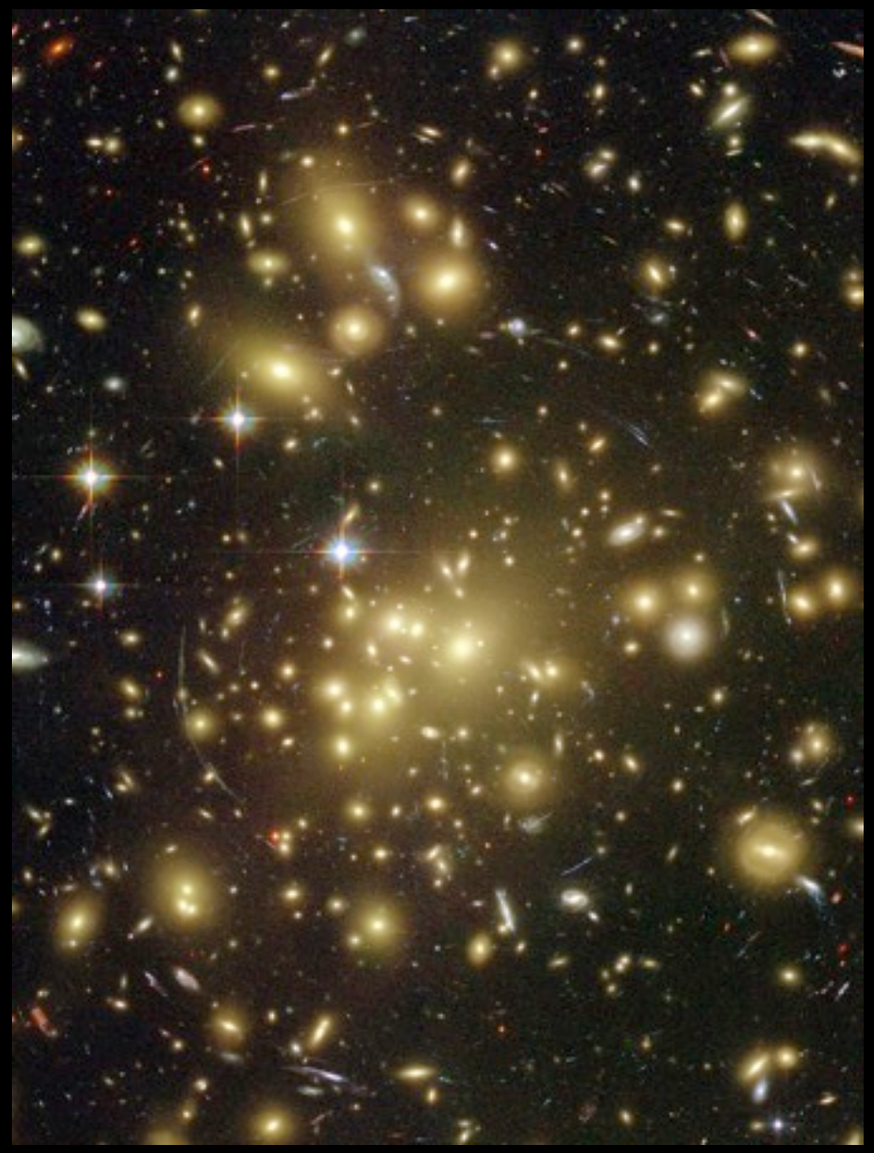
Powerful gravitational **lenses**

=> **Cosmic laboratories**

Cosmic laboratories

dark matter revealed through grav. lensing

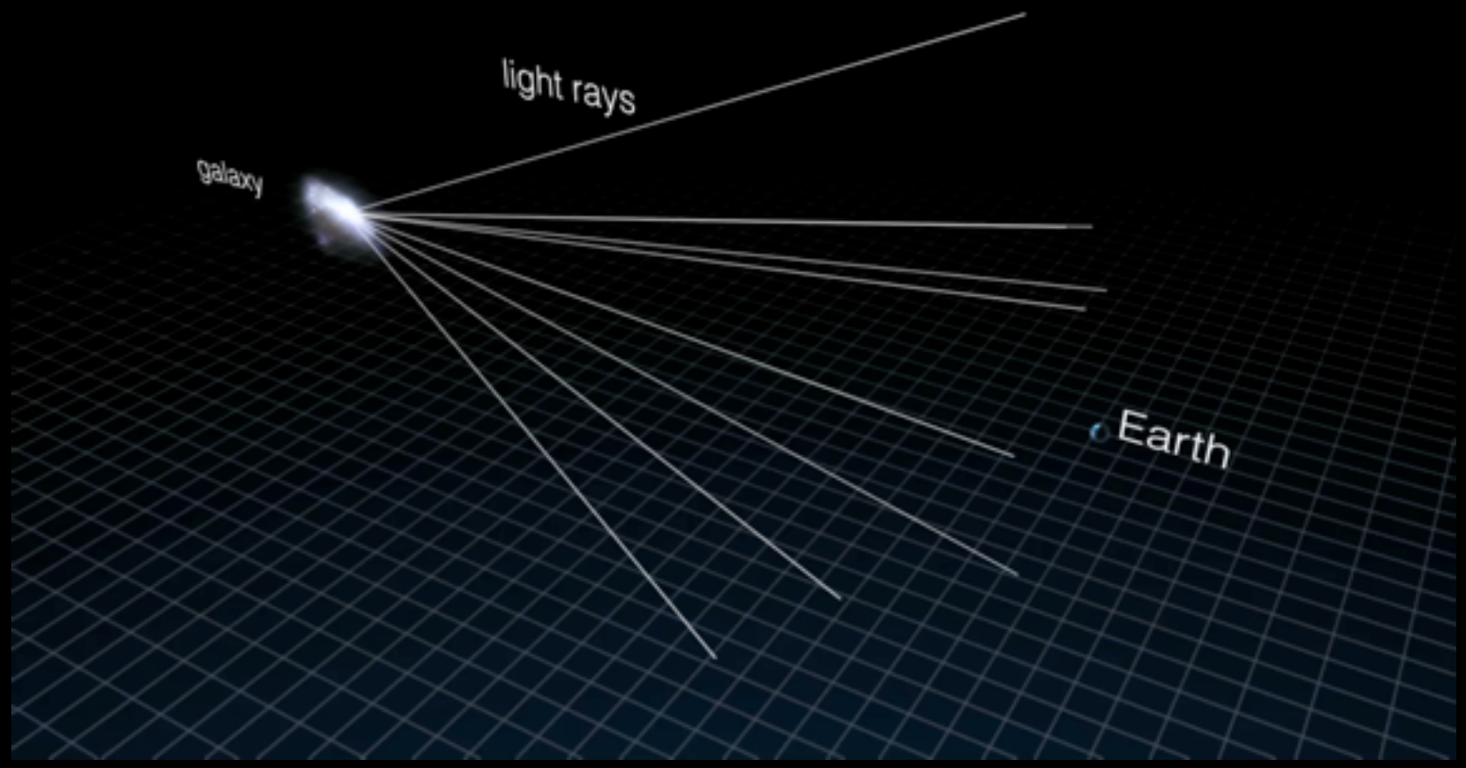
the galaxies and the gas
can be observed directly



computers create
simulated clusters
quite accurately

Cosmic laboratories

dark matter revealed through grav. lensing



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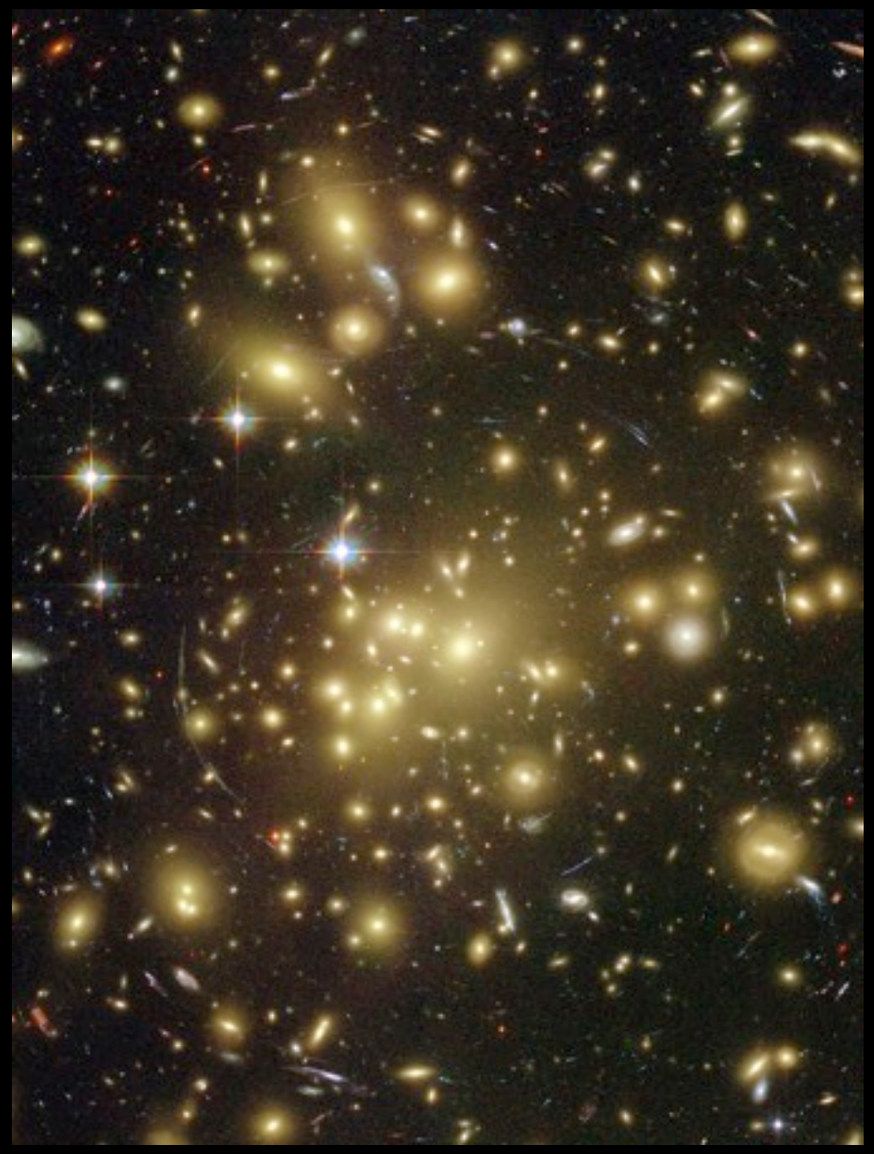

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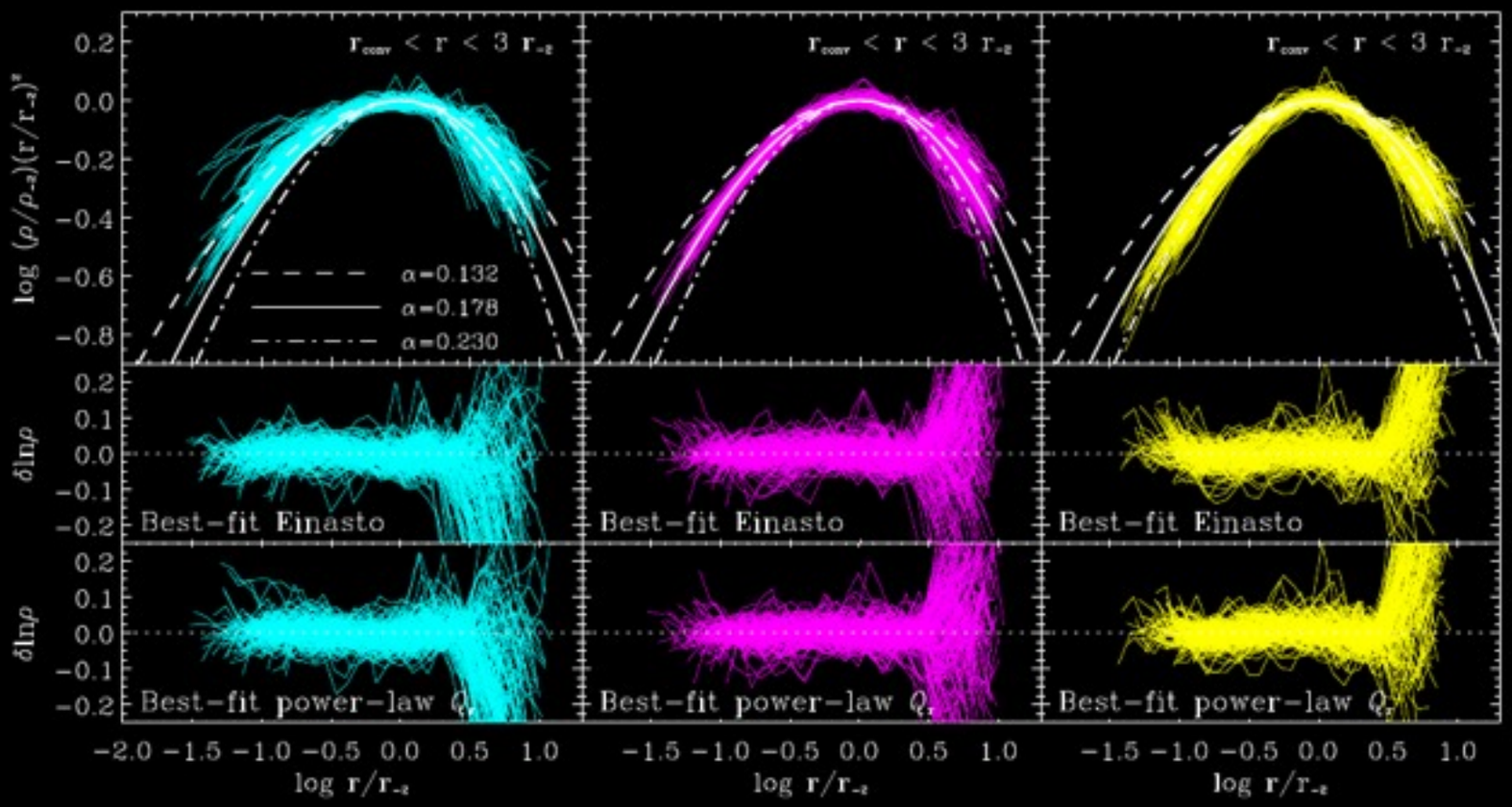
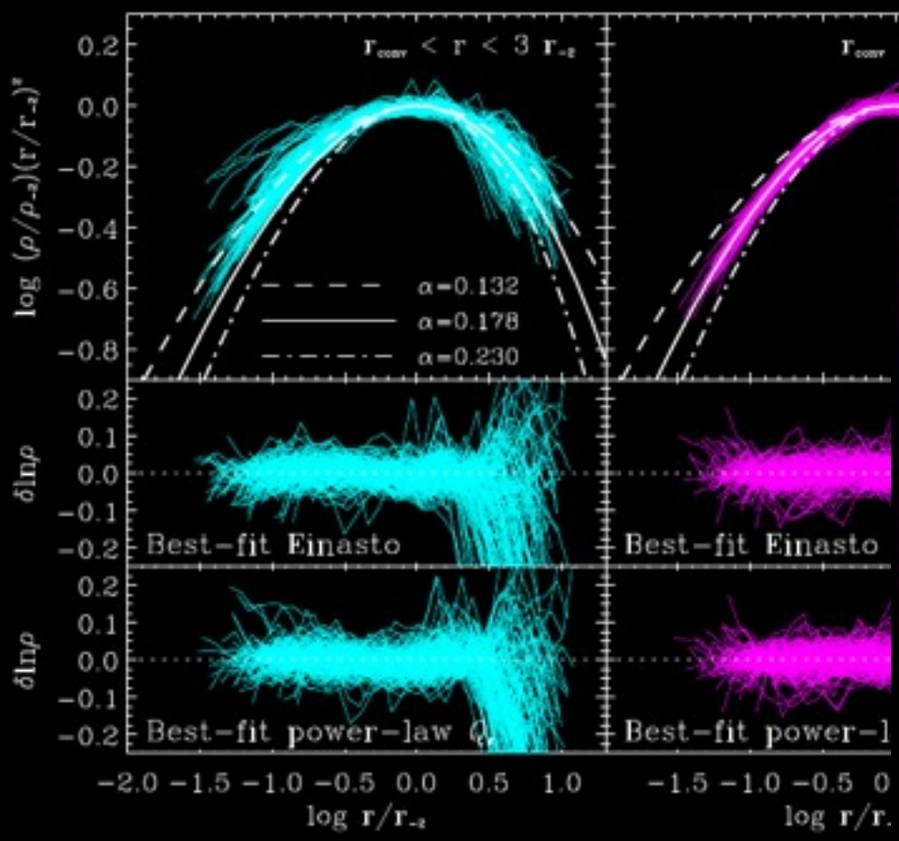
Puzzling clusters

Puzzling clusters



Ludlow+ 11

Puzzling clusters



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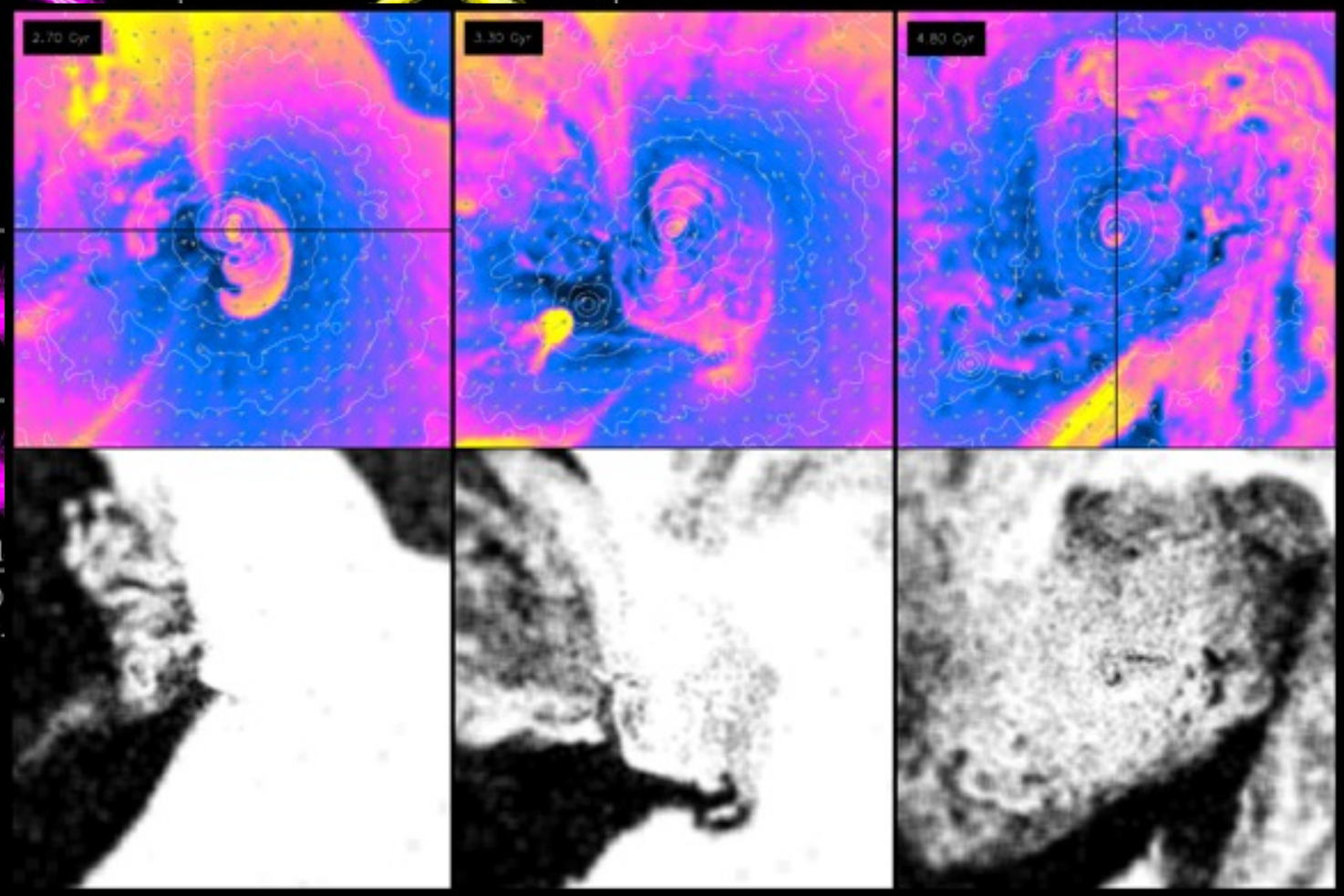
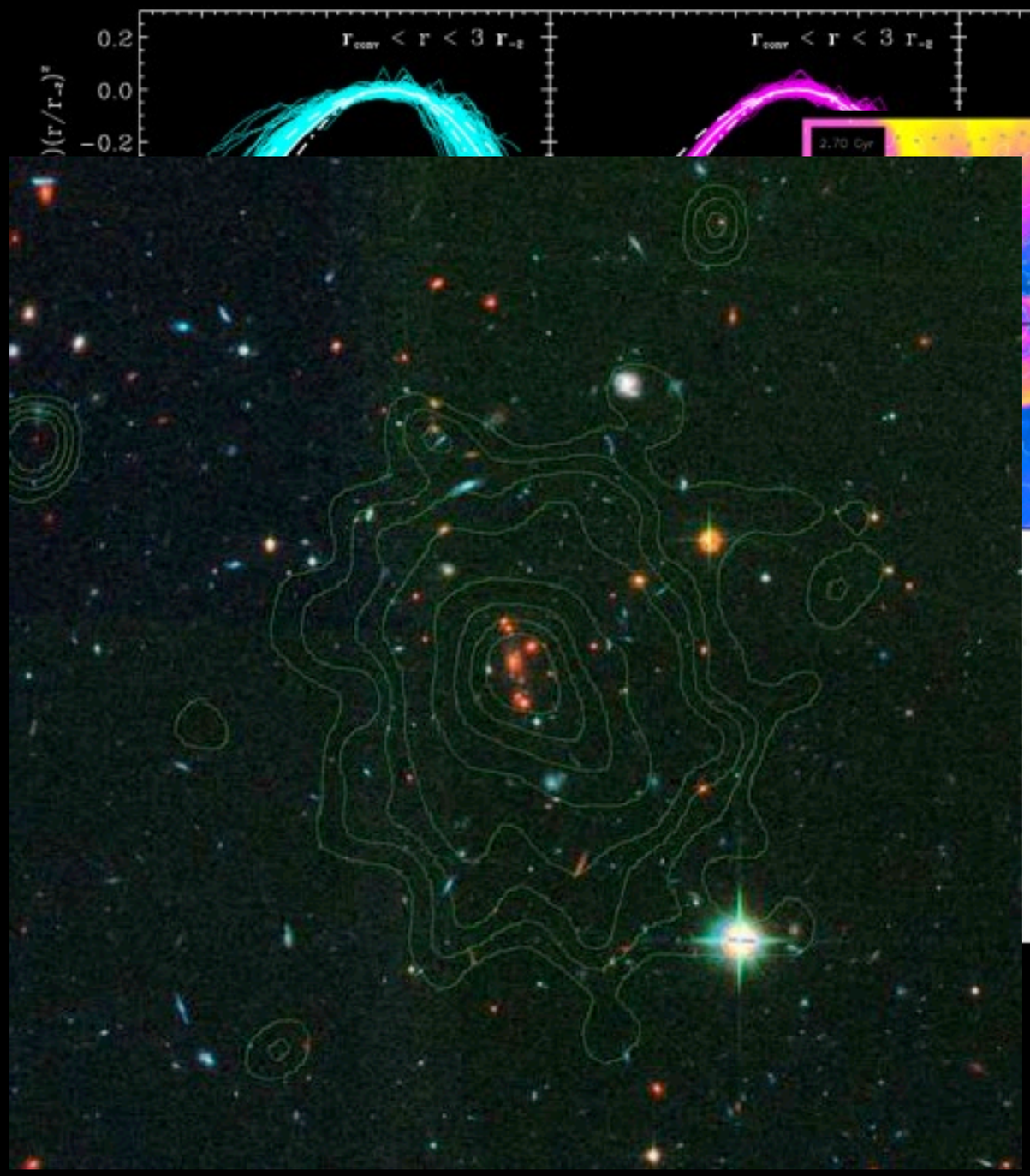
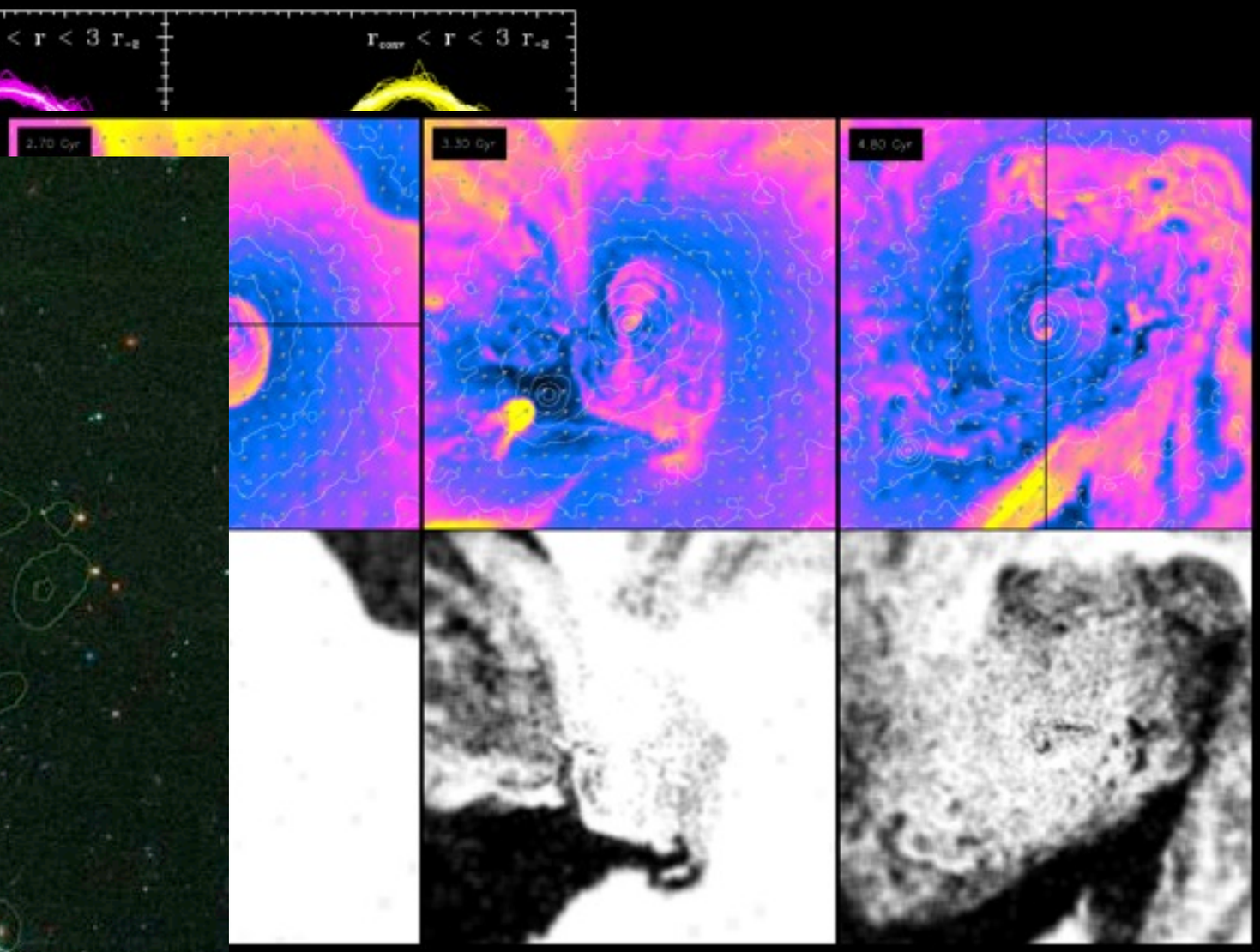


Ascasibar+ 06

Puzzling clusters



Rosati+ 09



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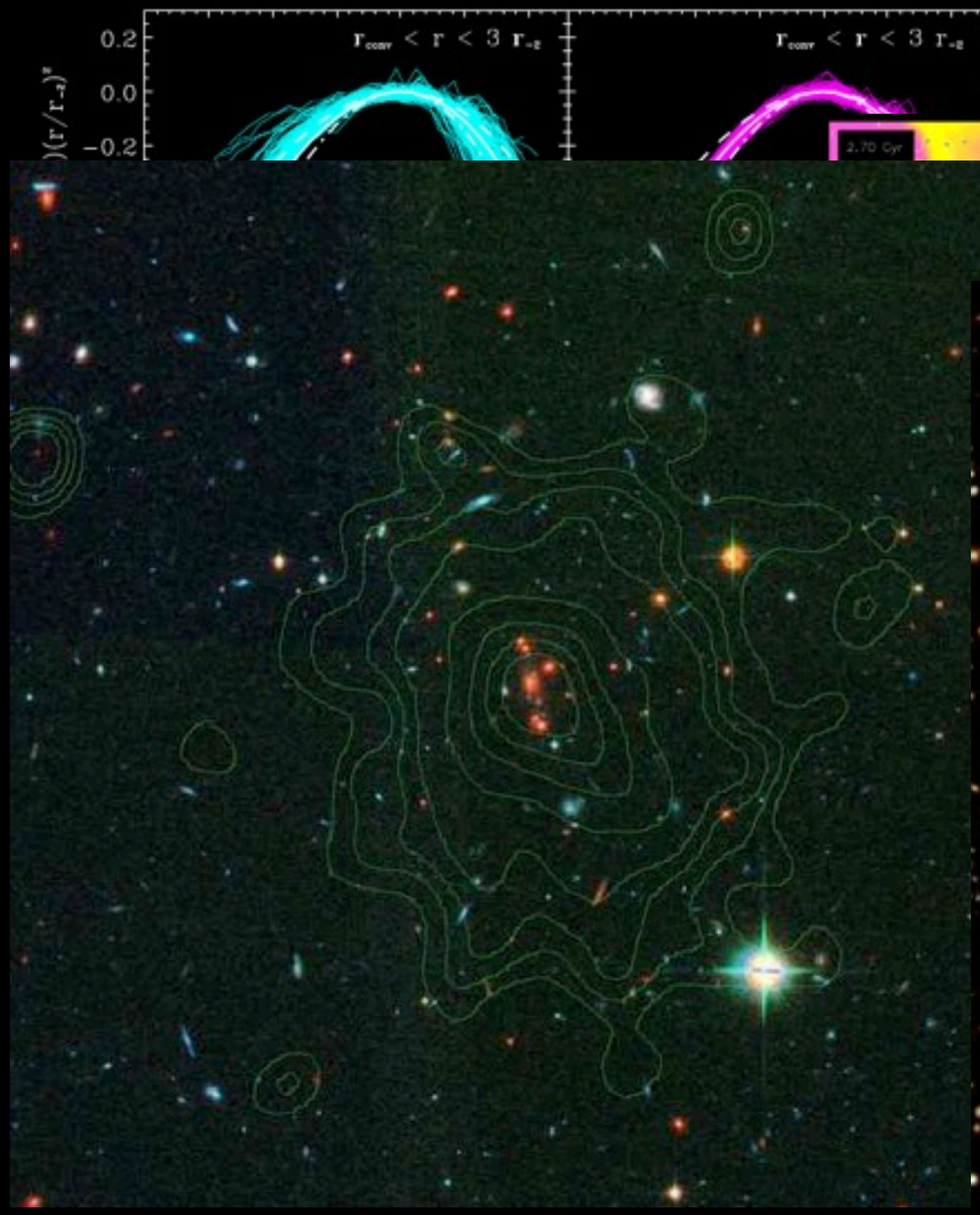
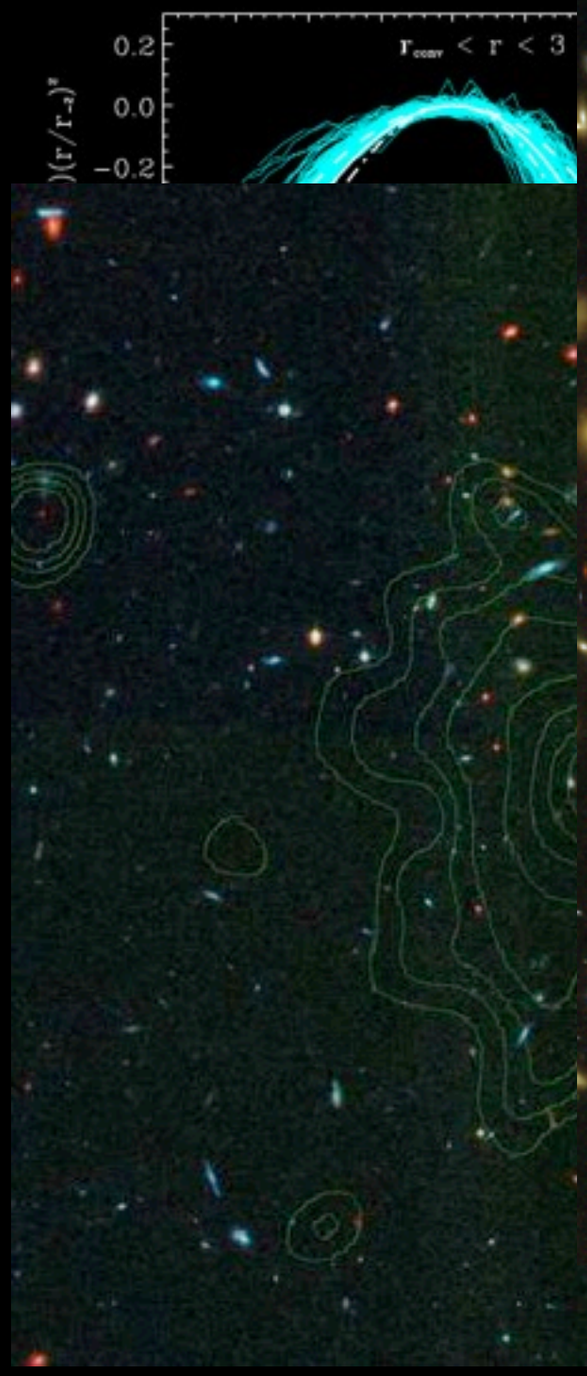
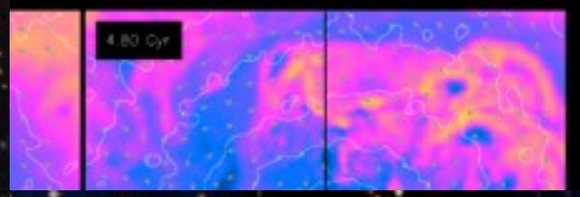


Rosati+ 09

Clowe+ 06

Puzzling clusters



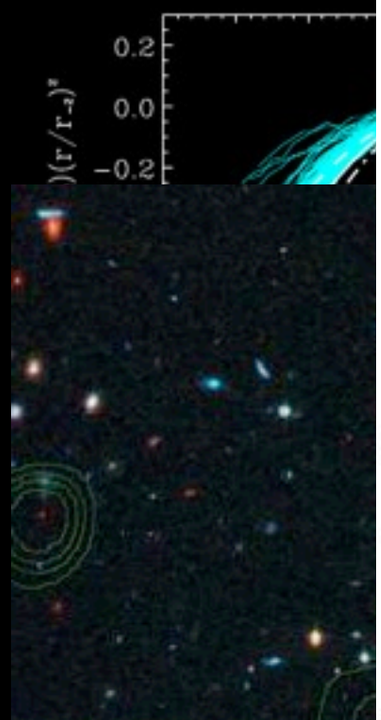


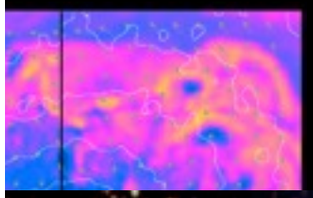
Coe+ 10

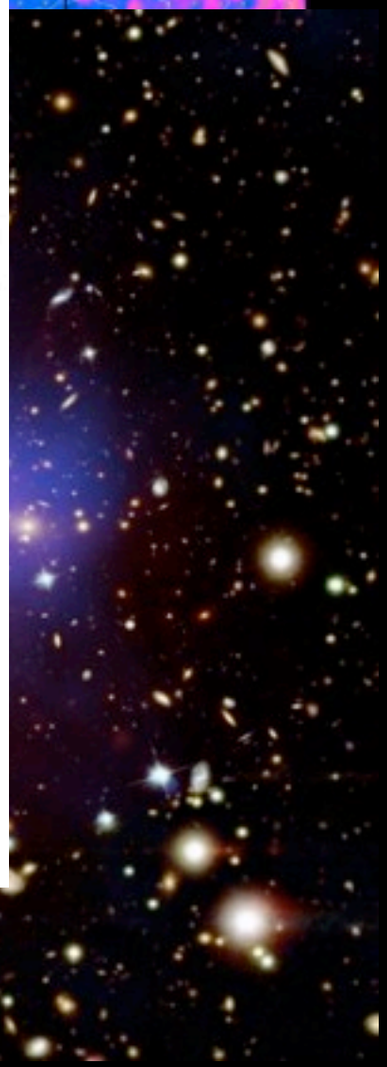
Rosati+ 09

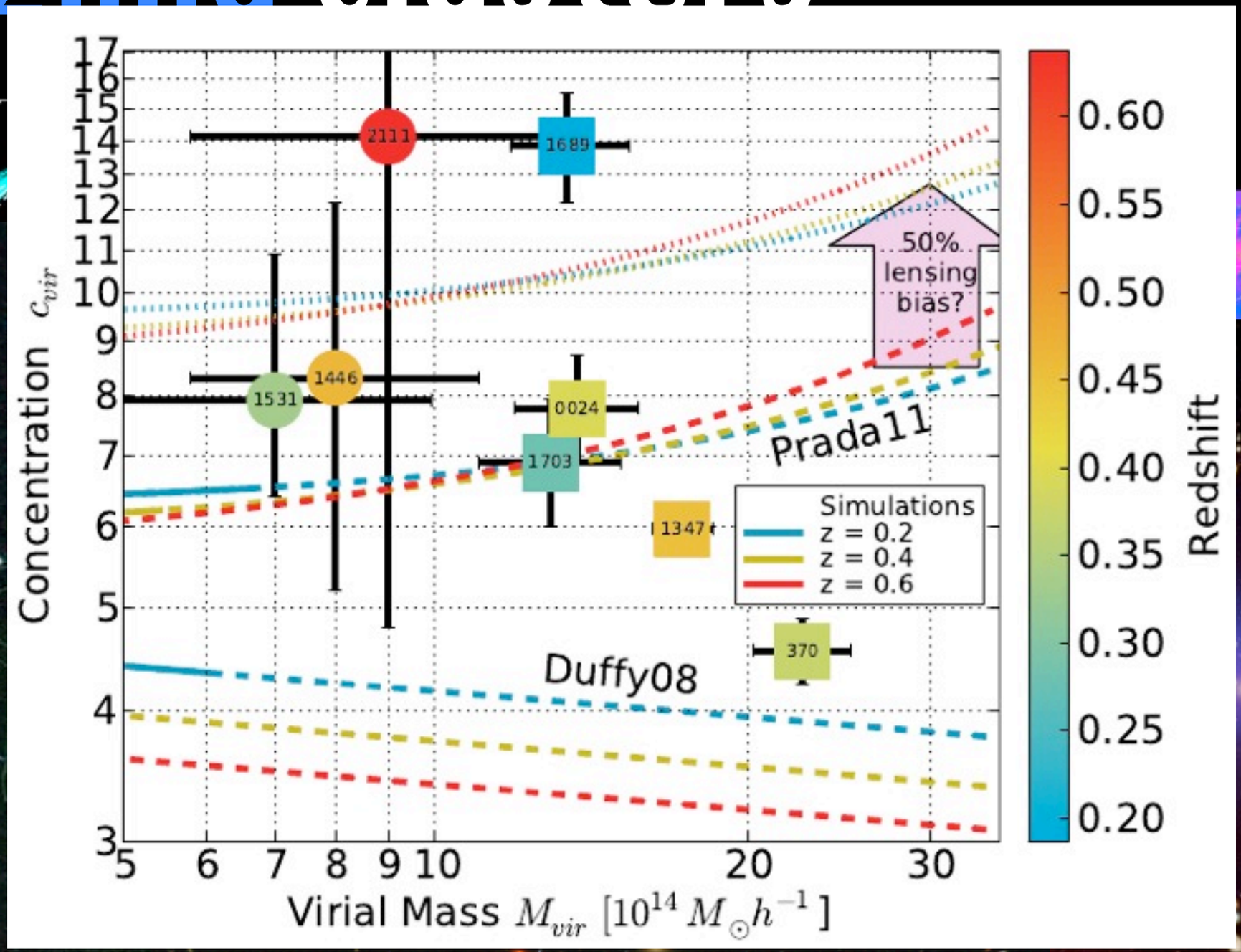
Clowe+ 06

Puzzling clusters









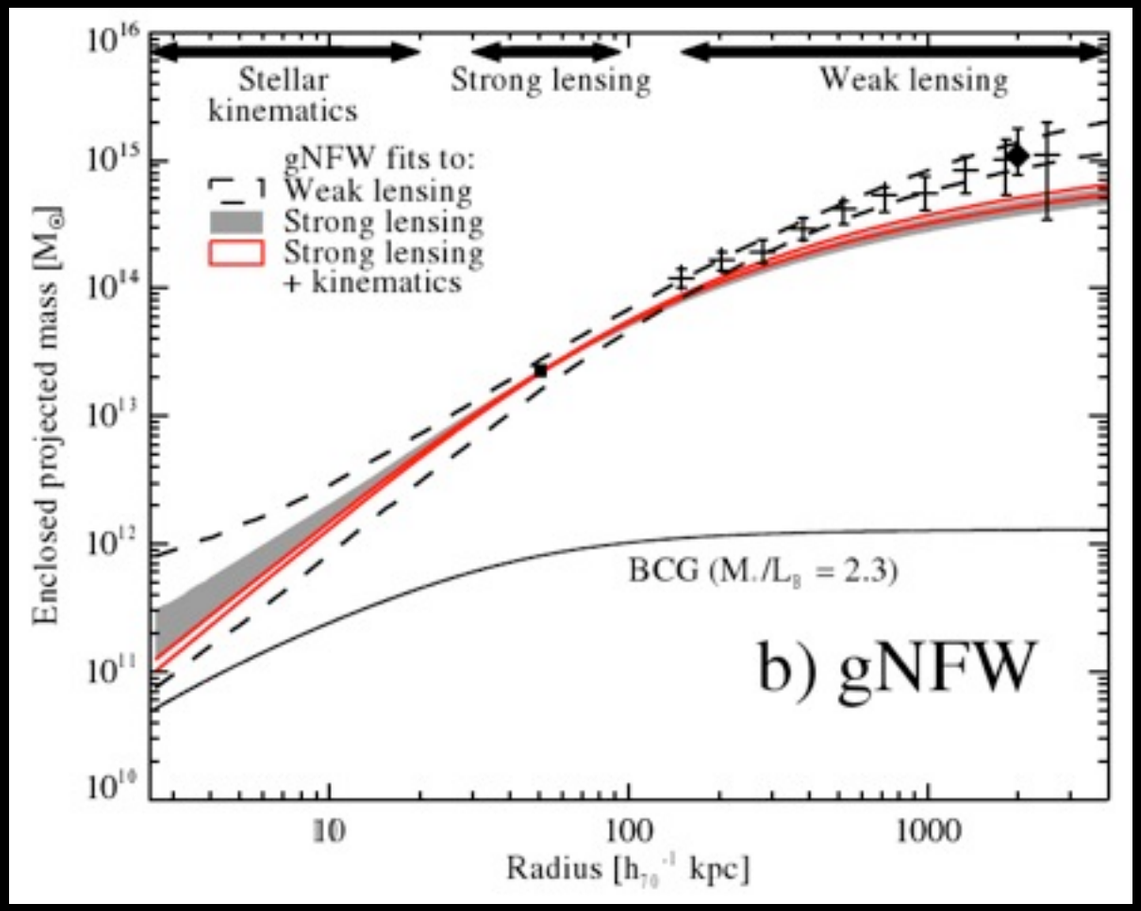
Postman & CLASH 11

Coe+ 10

Rosati+ 09

Clowe+ 06

Shedding light



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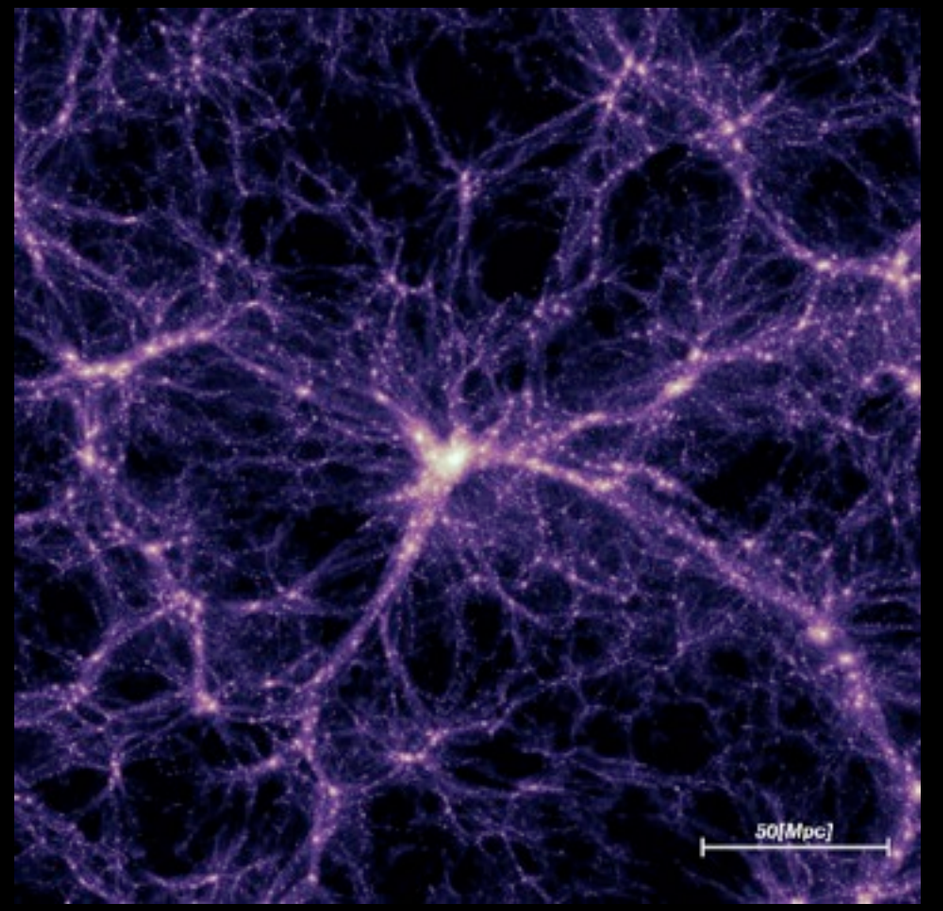
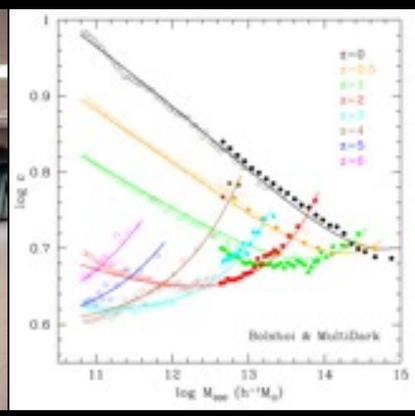




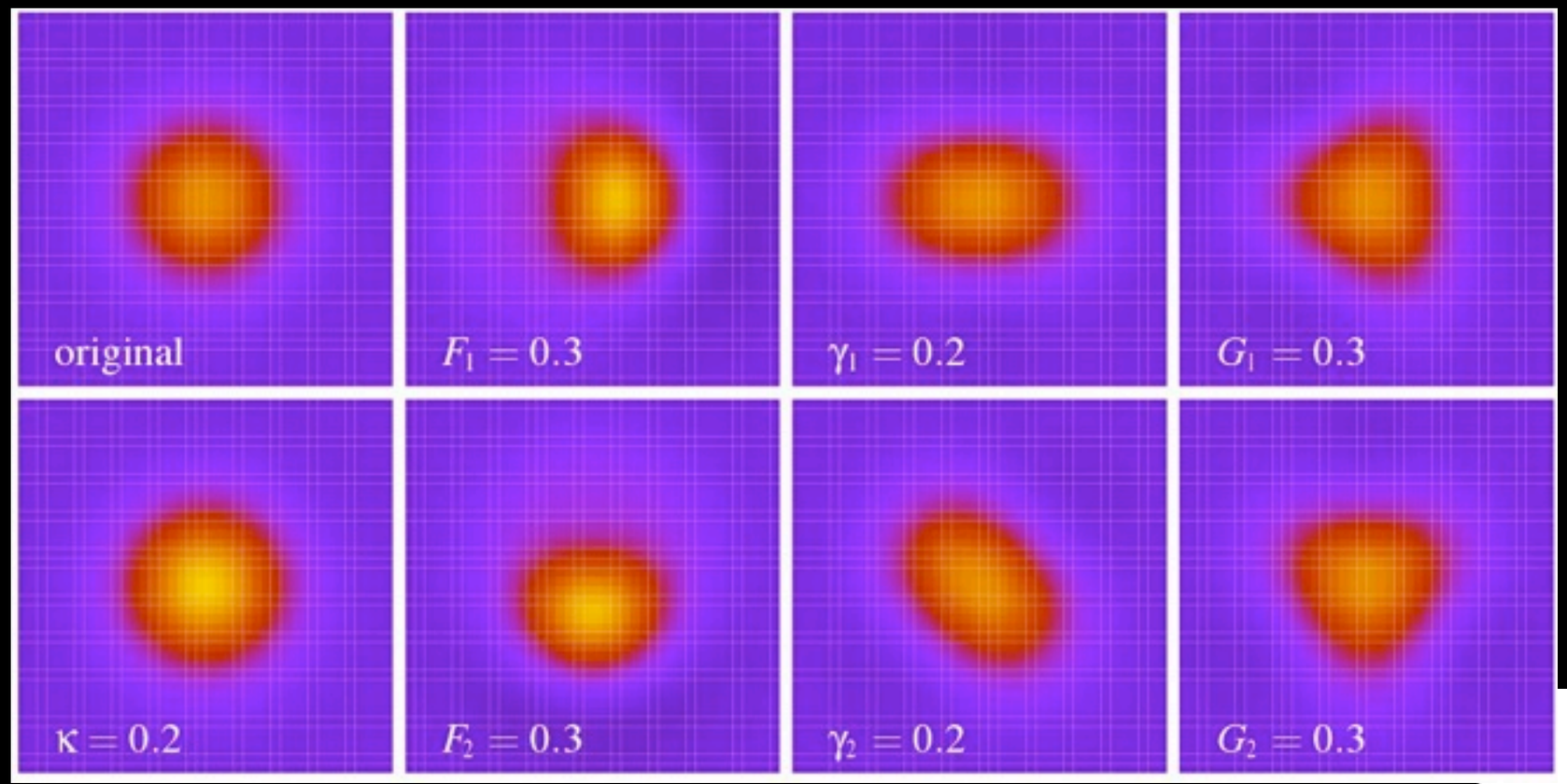
Real world

Cluster mass reconstructions

Wish list	Solution
nonparametric	grid-based approach
wide range of scales	AMR
multiple constraints	multicomponent chi^2
single fit	reconstruct lensing potential
fast also with errors	massively parallel implementation

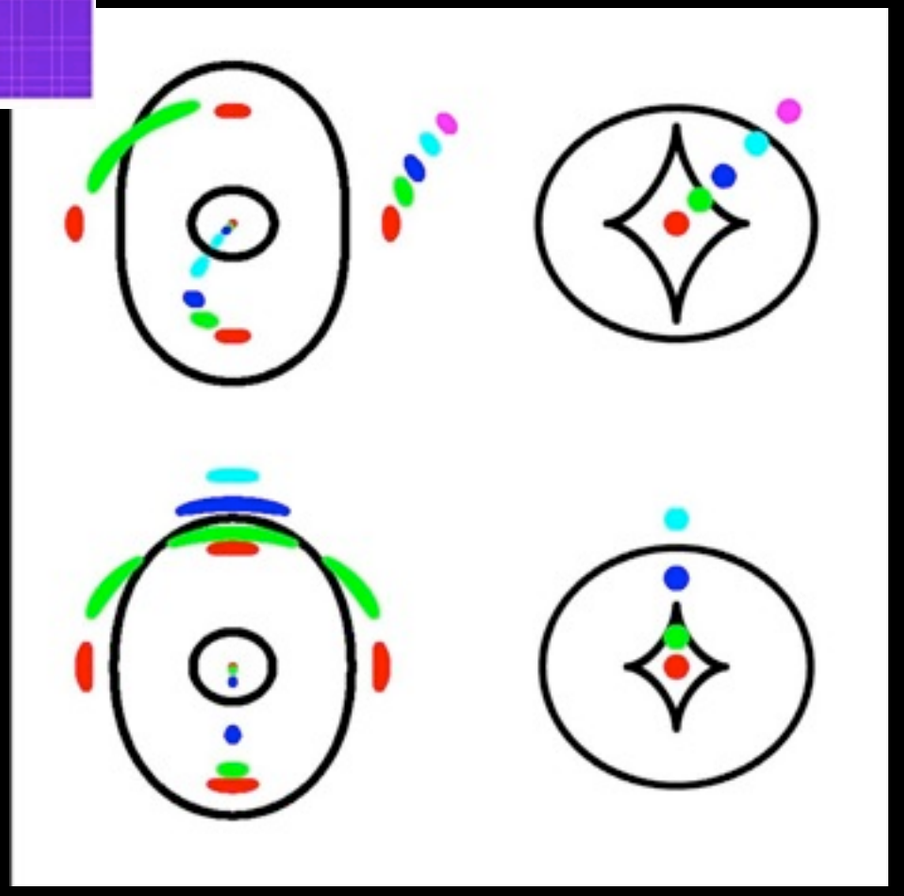
Useful observational constraints

Gravitational lensing



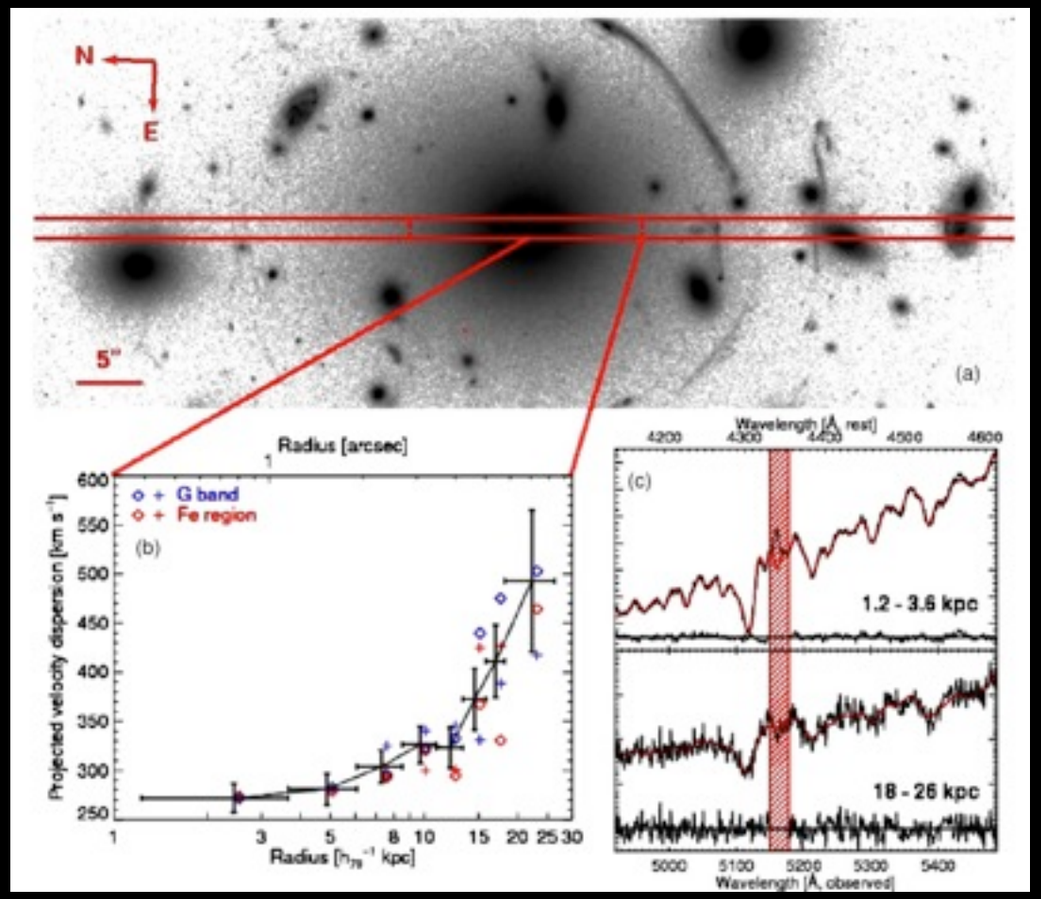
Astronomy picture of the day Oct. 17

CLASH collab.

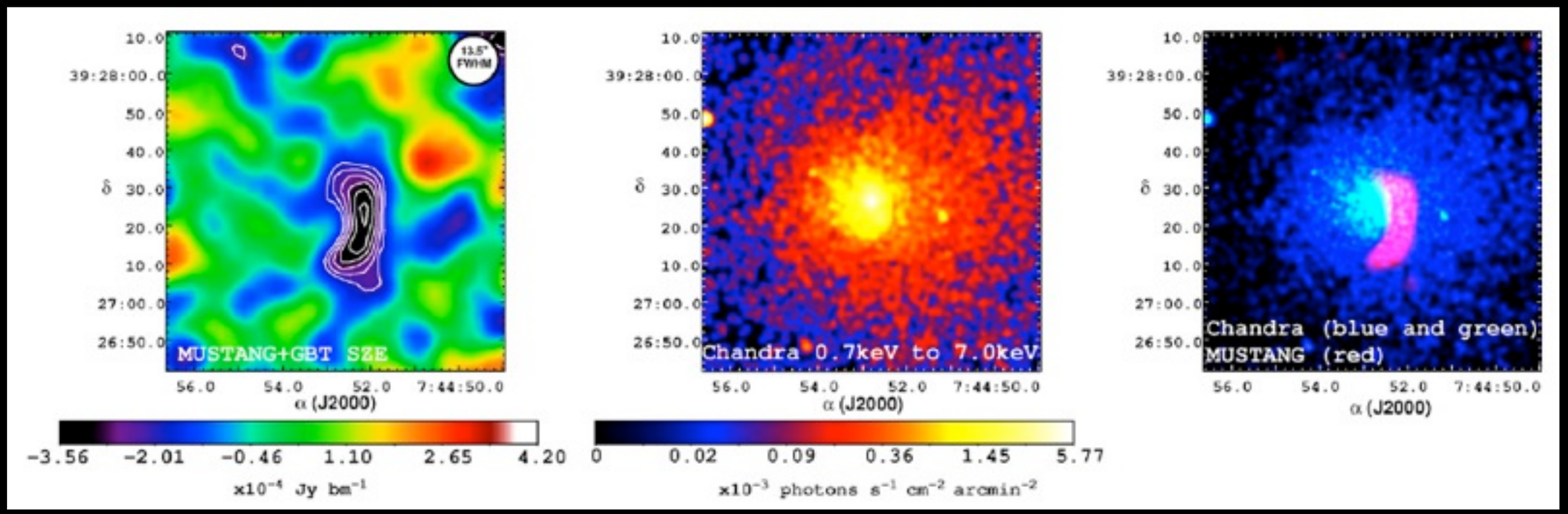


Still to come

Charles Majer, Eleonora Sarli & Agnese Fabris working on that

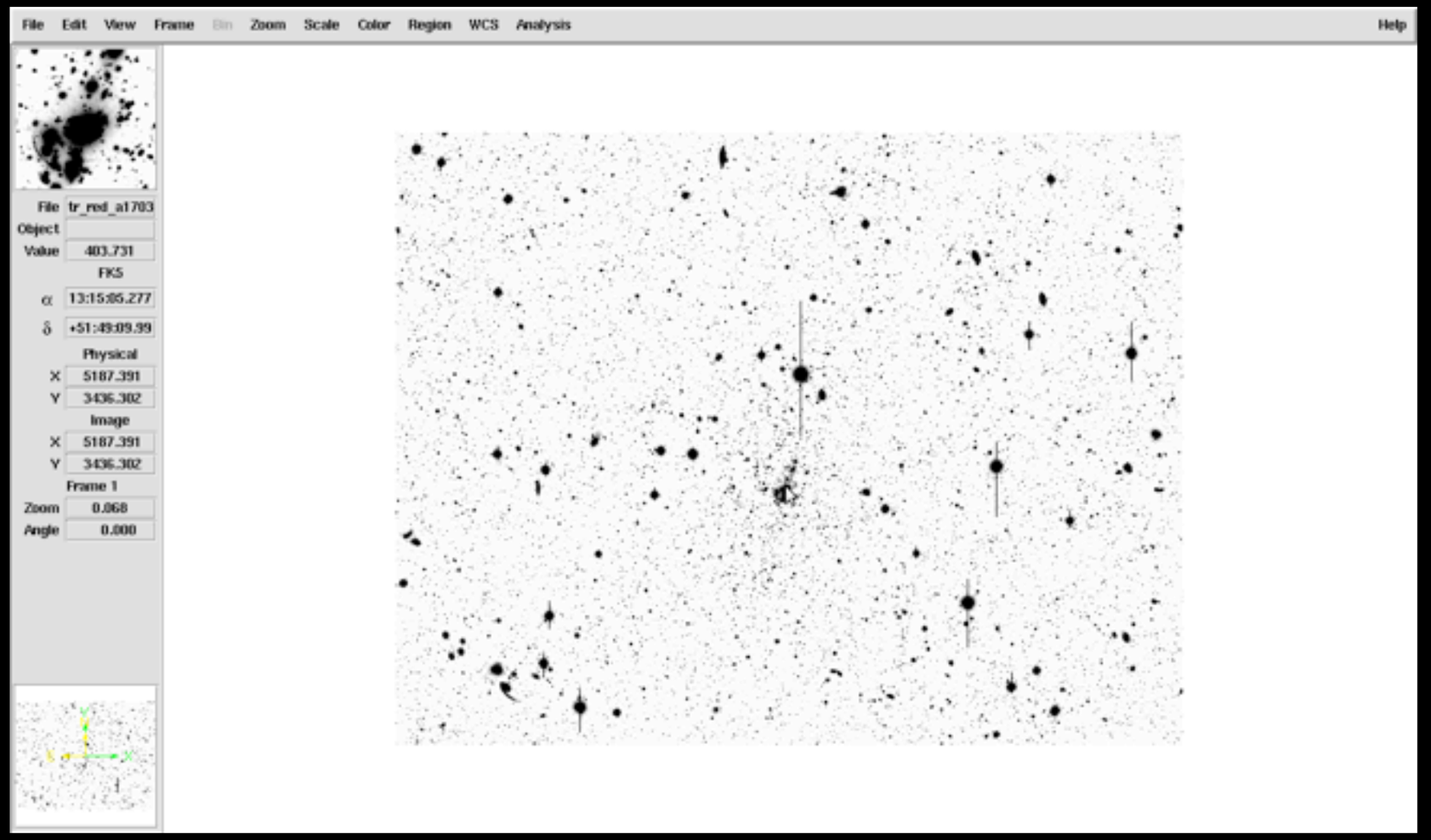


Newman 11+



Korngut 11+

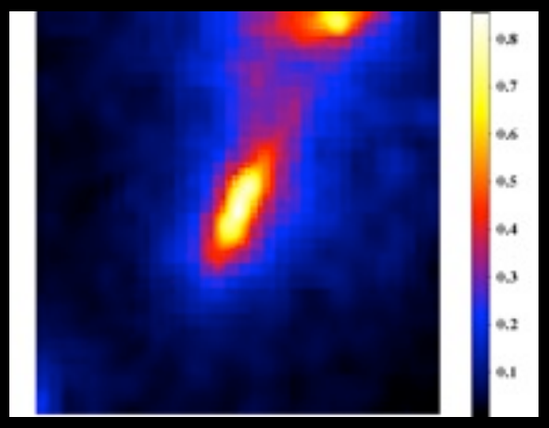
Numerical implementation

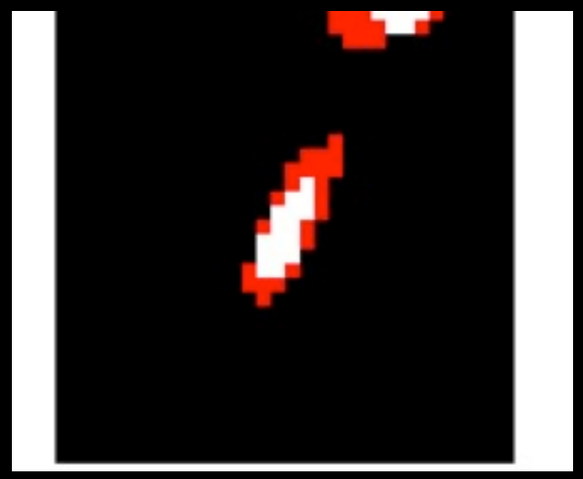


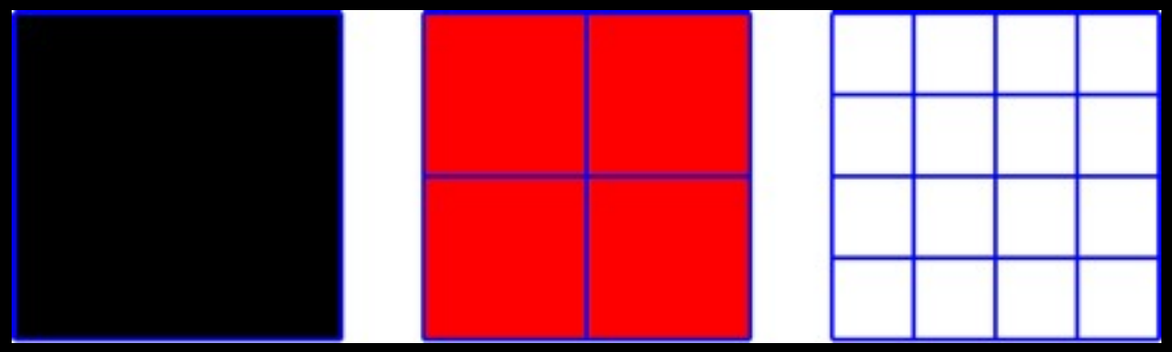
A

M

R







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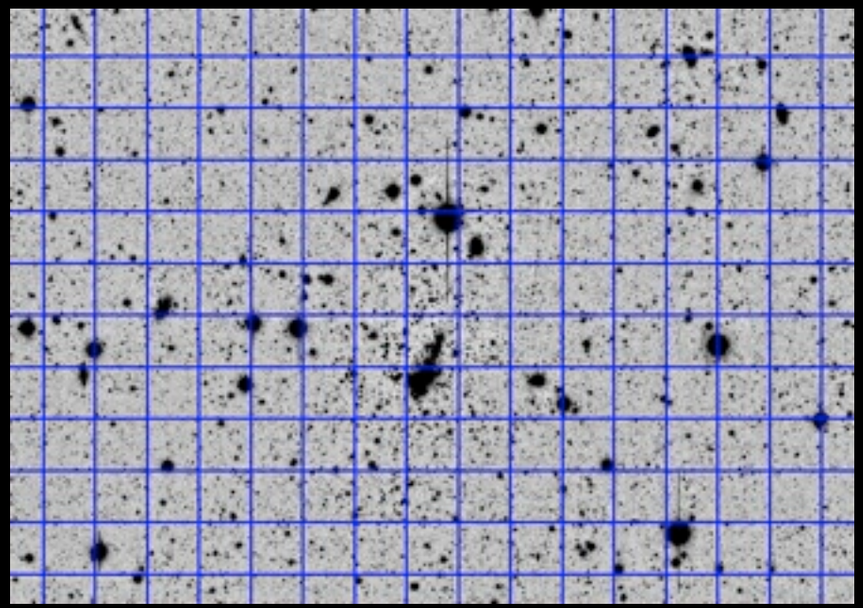
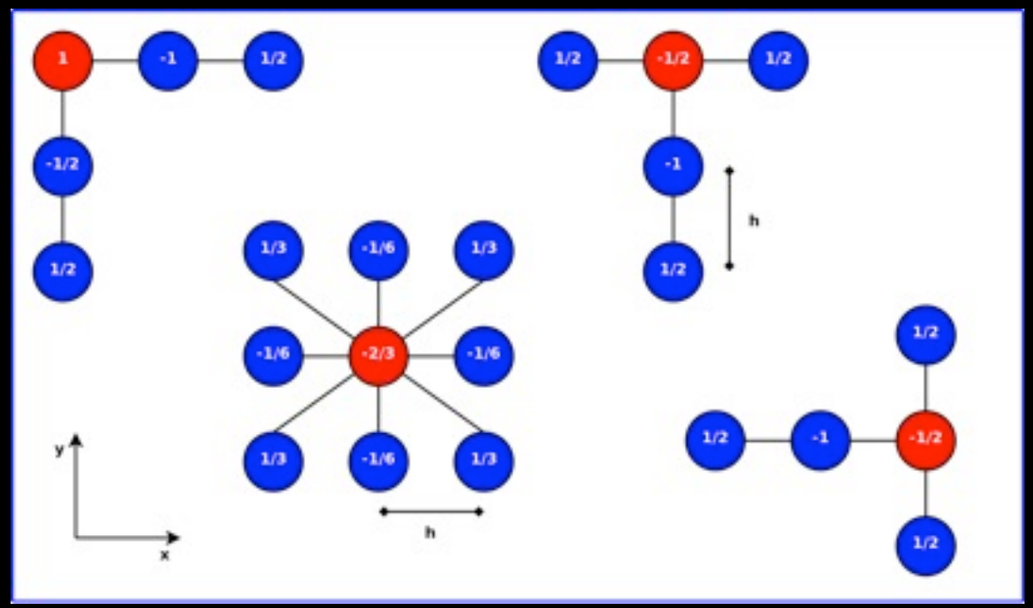




Finite differencing on the grid

Cluster lensing in a box

$$\beta = \theta - \alpha(\theta)$$

$$\partial = \partial_1 + \mathrm{i}\partial_2 \qquad \partial^* = \partial_1 - \mathrm{i}\partial_2$$

$$\psi \qquad \alpha = \partial\psi$$

$$2\gamma = \partial\partial\psi \qquad 2\kappa = \partial^*\partial\psi$$

$$2F = \partial^*\partial\partial\psi \qquad 2G = \partial\partial\partial\psi$$

Problem Runtime

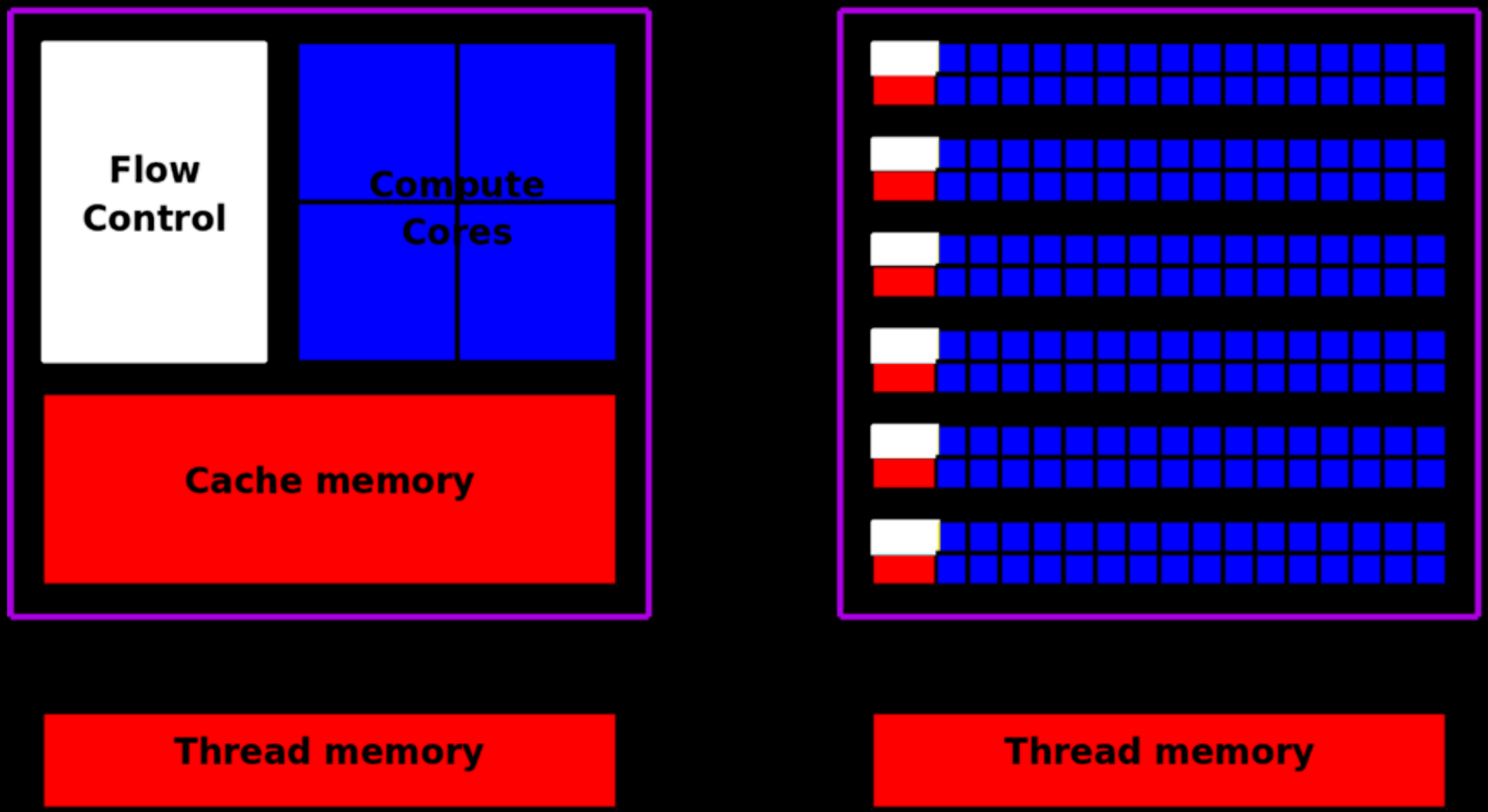
$$\mathcal{B}_{lk}\psi_k = \mathcal{V}_l$$

$$\mathcal{B}_{lk} \sim a_i b_j C_{ij} D_{il} E_{jk}$$

$$\mathcal{V}_l \sim a_i b_j C_{ij} E_{il}$$

$$l, k, i, j \sim \mathcal{O}(\mathrm{grid\_dim}^2)$$

Graphics processing units



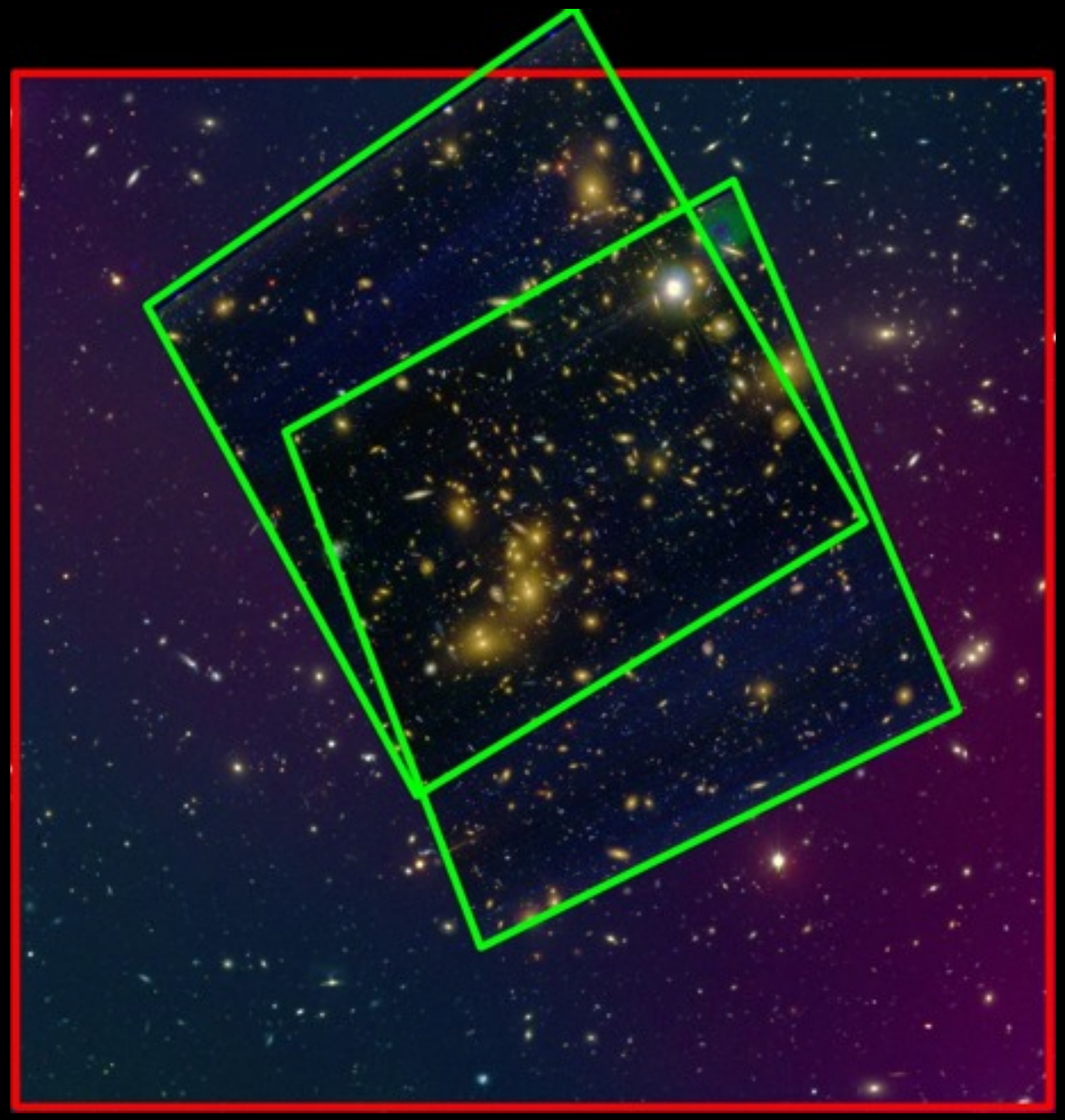
Intrinsically massively parallel chip design

Graphics processing units

We aquired new hardware,
current speedup ~100,
pipeline development for Euclid, LSST, etc...

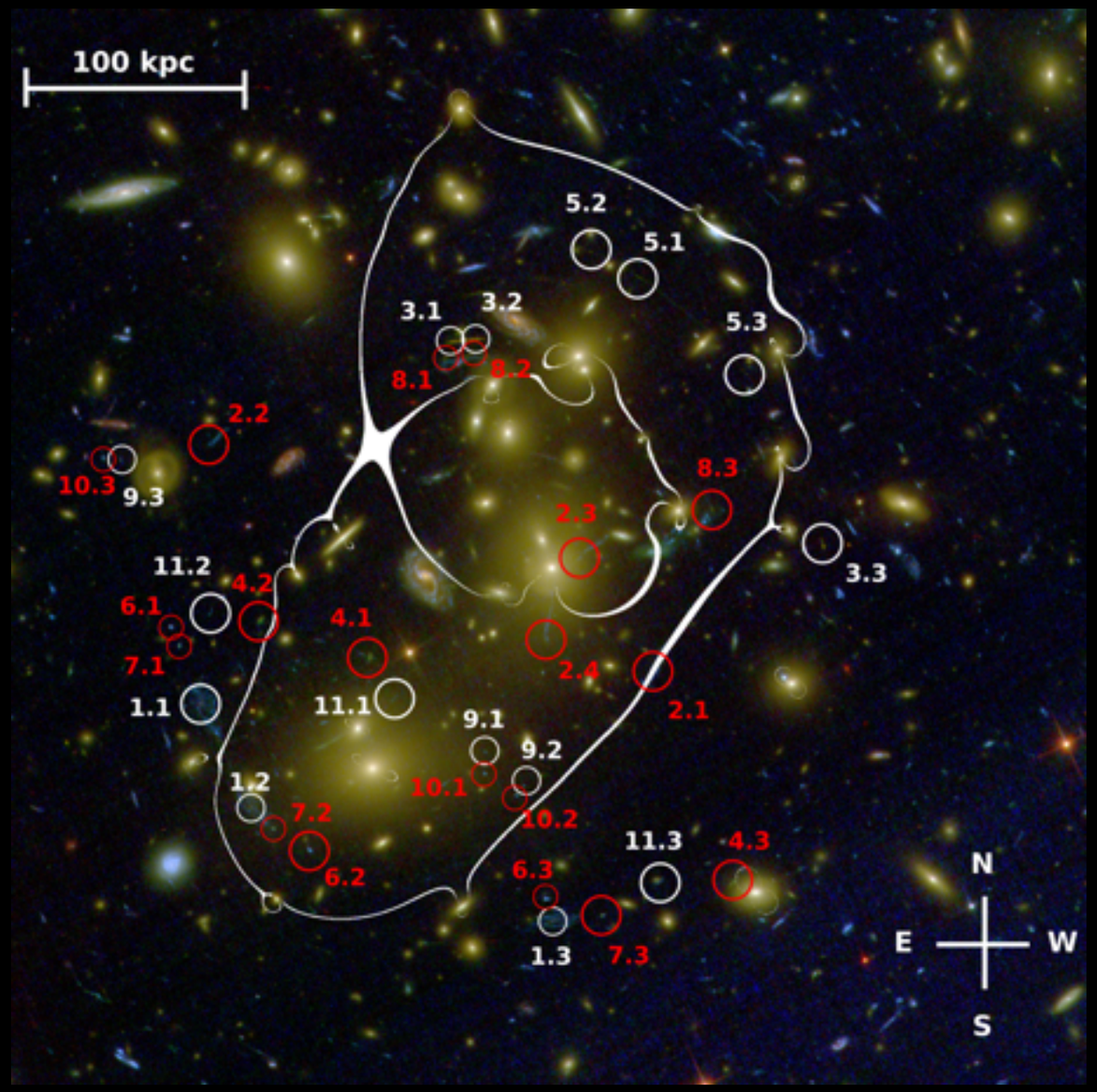
Applications

The case of Abell 2744



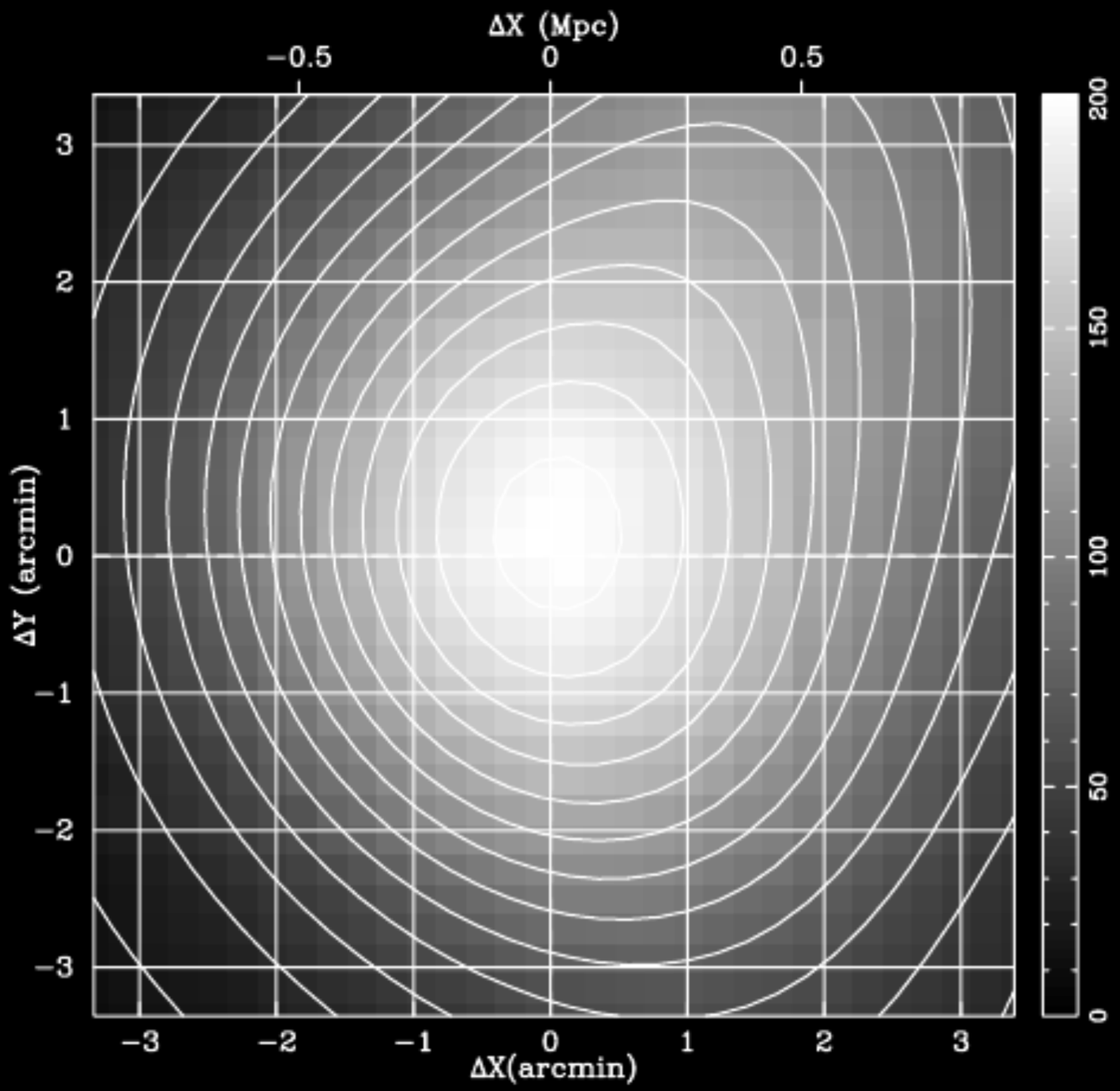
8 Orbits in Hubble Cycle17, PI: R. Dupke

The case of Abell 2744



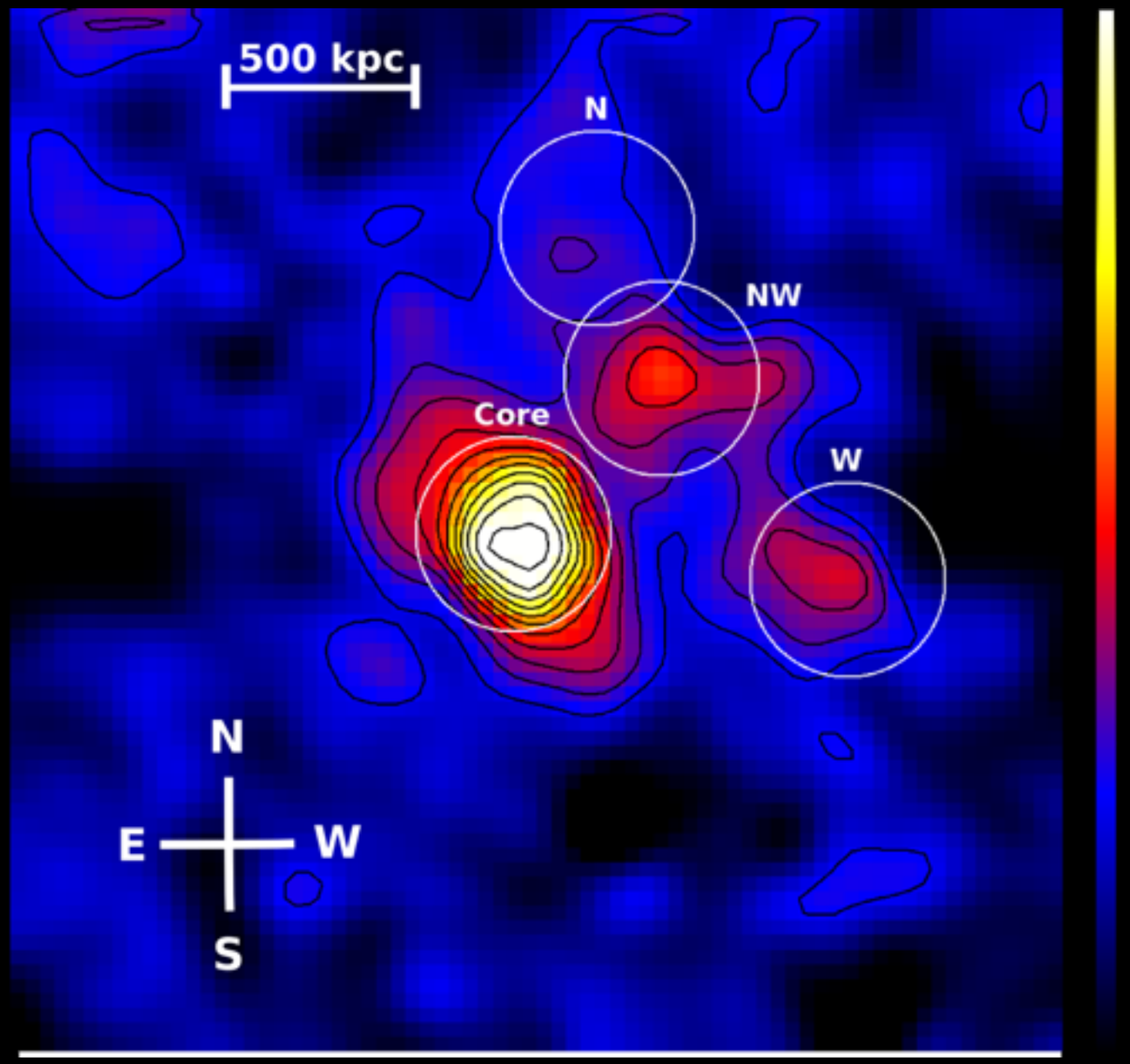
JM+ 11, we identified 34 multiple images

The case of Abell 2744



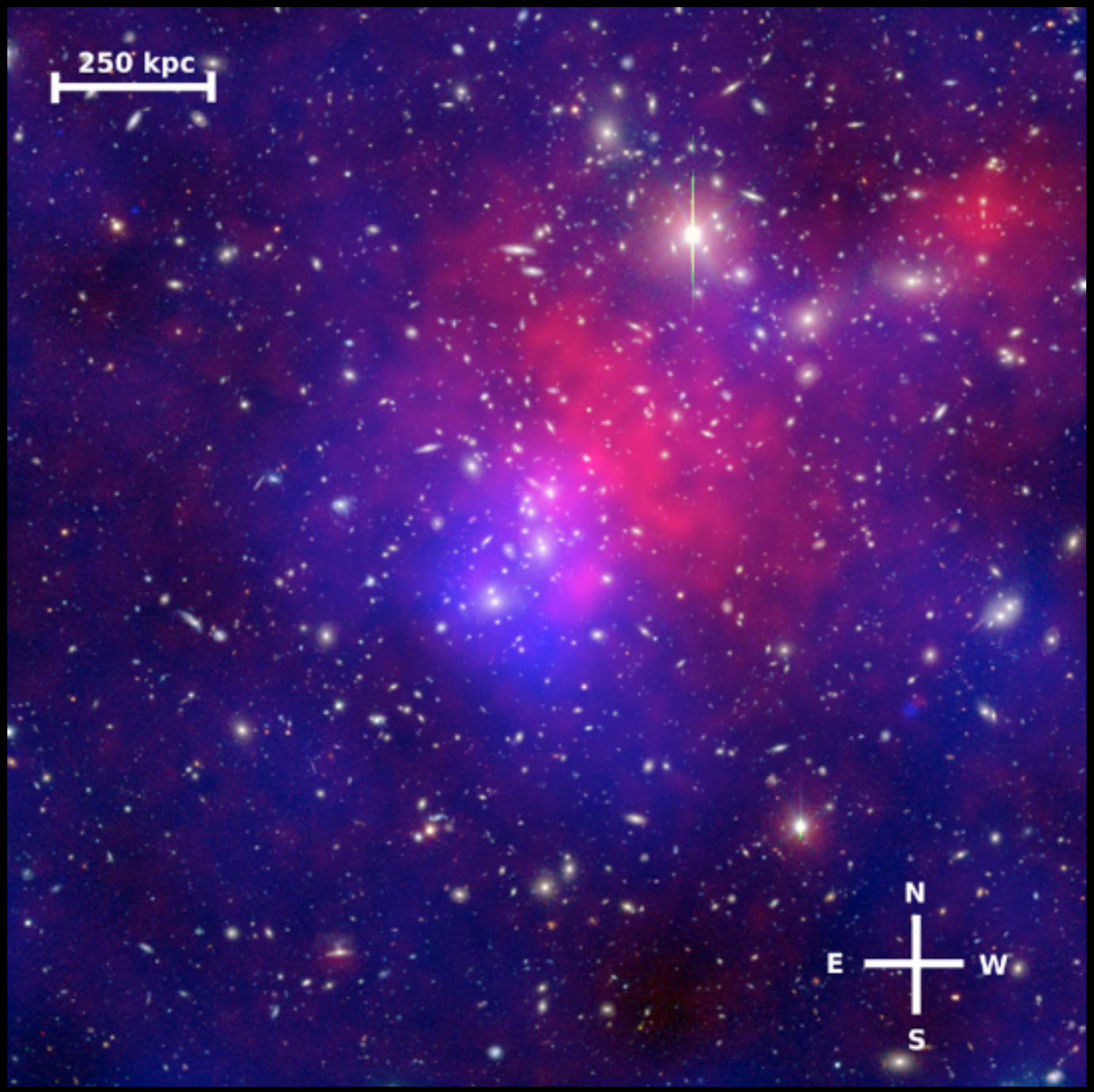
before

The case of Abell 2744



JM+11, MNRAS in press

Pandora's Cluster

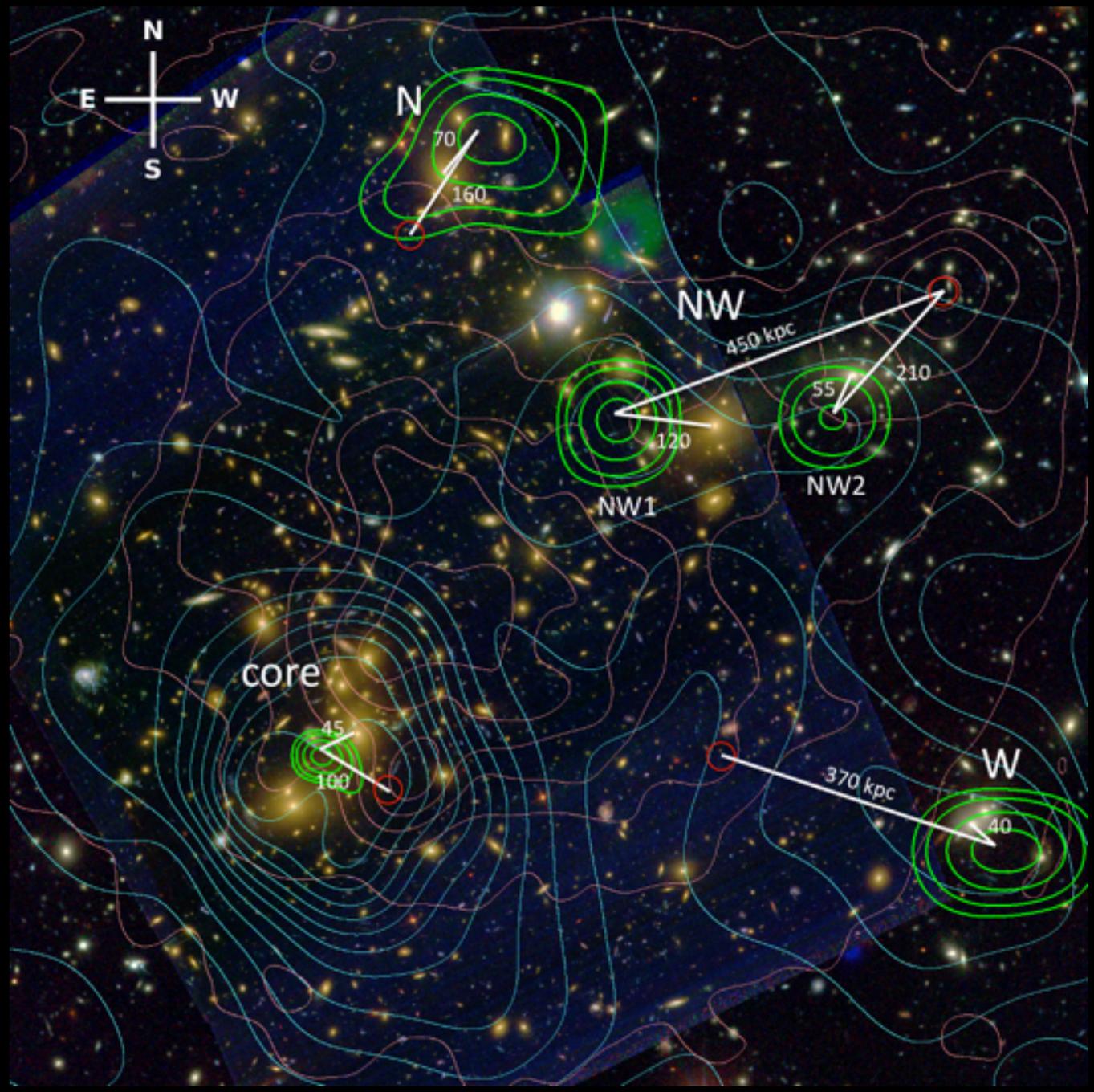


Astronomy picture of the day Jun. 29

Merten & Coe

NASA, ESA, CXC, D. Coe & J. Merten

Pandora's Cluster



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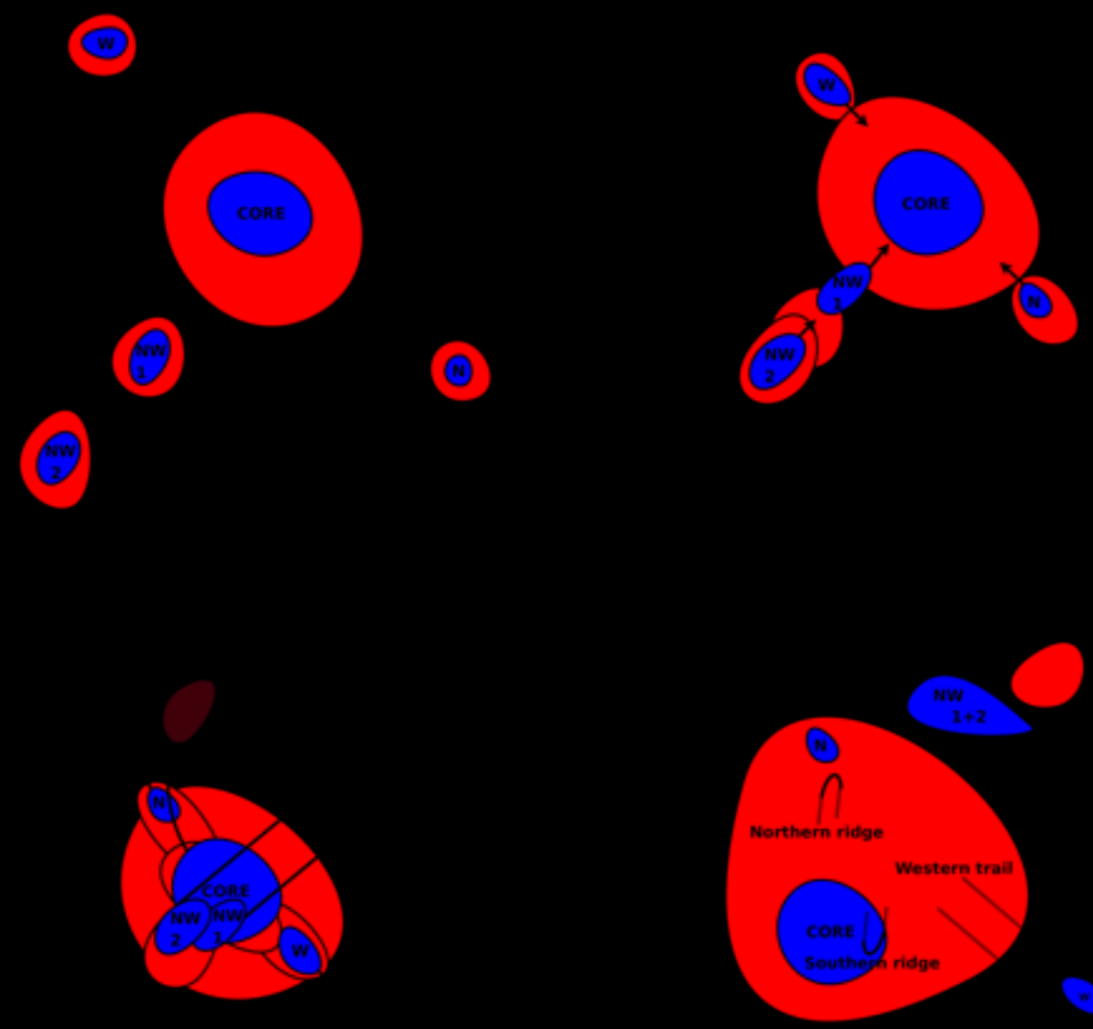


JM+ 11

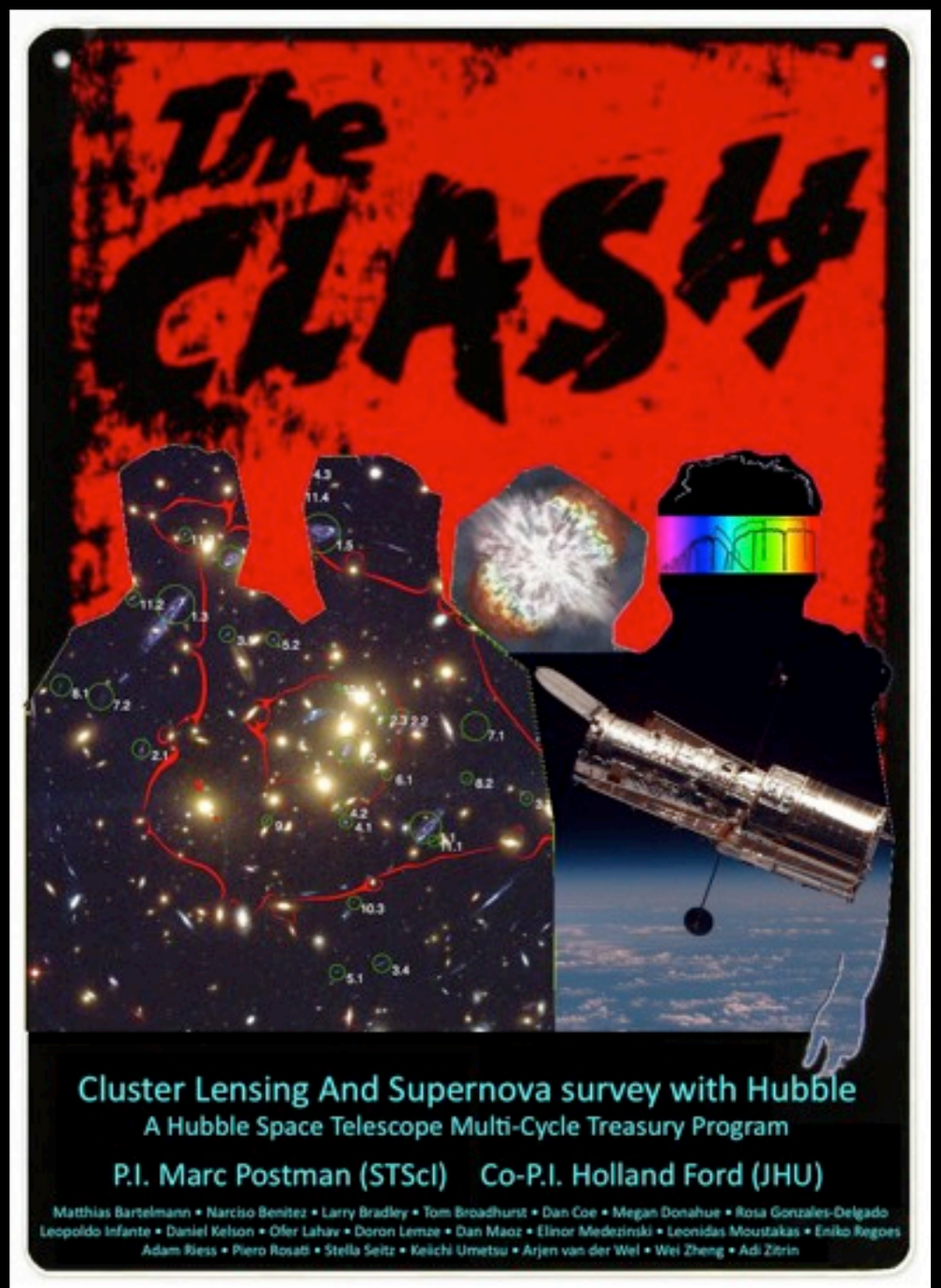
This will become a real challenge for simulations

Collaboration with V. Springel's group in Heidelberg

A first search in MXXL was already successful

The CLASH

One of three HST/MCT programmes ~550 orbits



Science Drivers

To map the DM profile and substructure to unprecedented precision

To detect SN Ia out to z ~ 2.5

To detect and analyse galaxies out to z > 7

To study the structure and evolution of galaxies in and behind the clusters

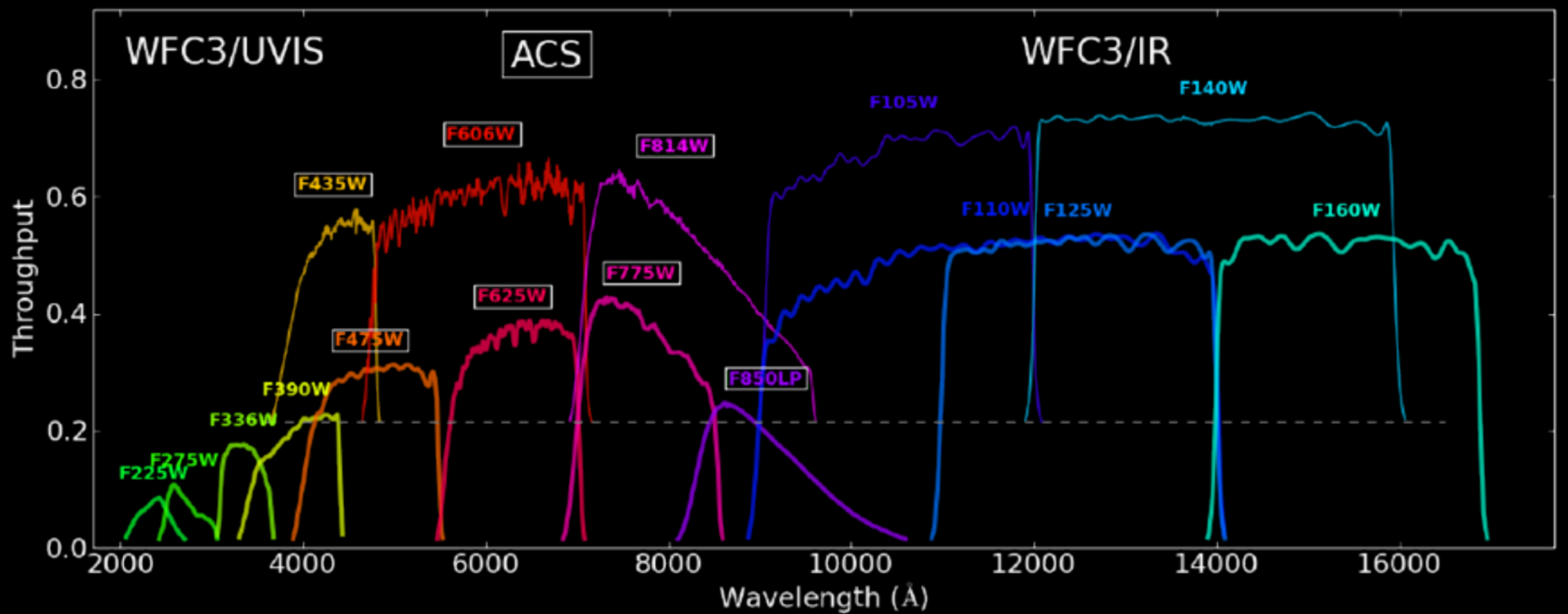
The team

Granada, autumn of 2010

The team

Heidelberg, two weeks ago

The observing programme



25 clusters

20 orbits and 16 filters /cluster

20 X-ray selected

ACS/WFC3 in parallel

5 spec. lenses

excellent photo z's

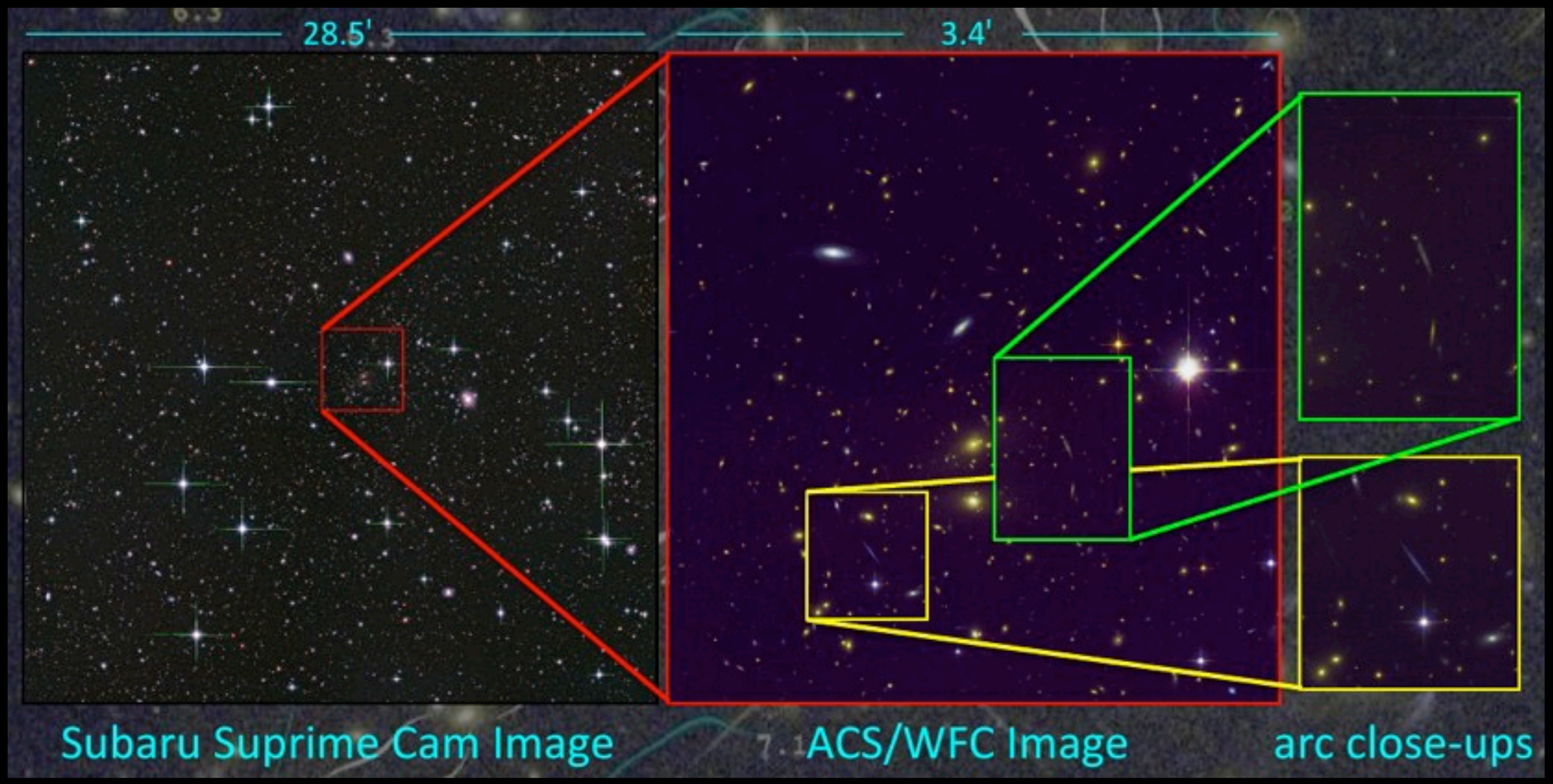
0.18 < z < 0.9

BPZ / LePhare

use Hubbles full power

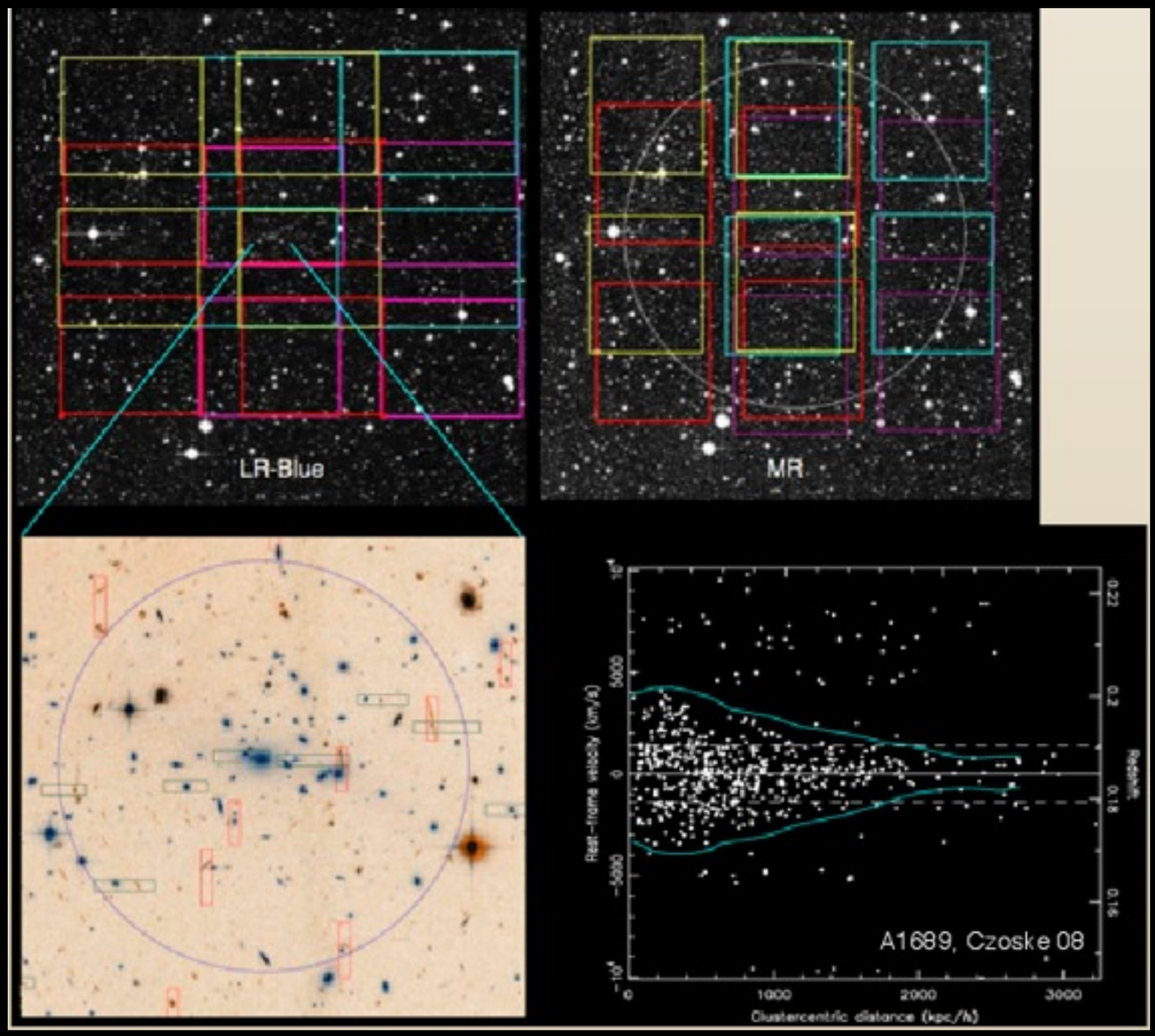
follow-up time > CLASH

That's not all



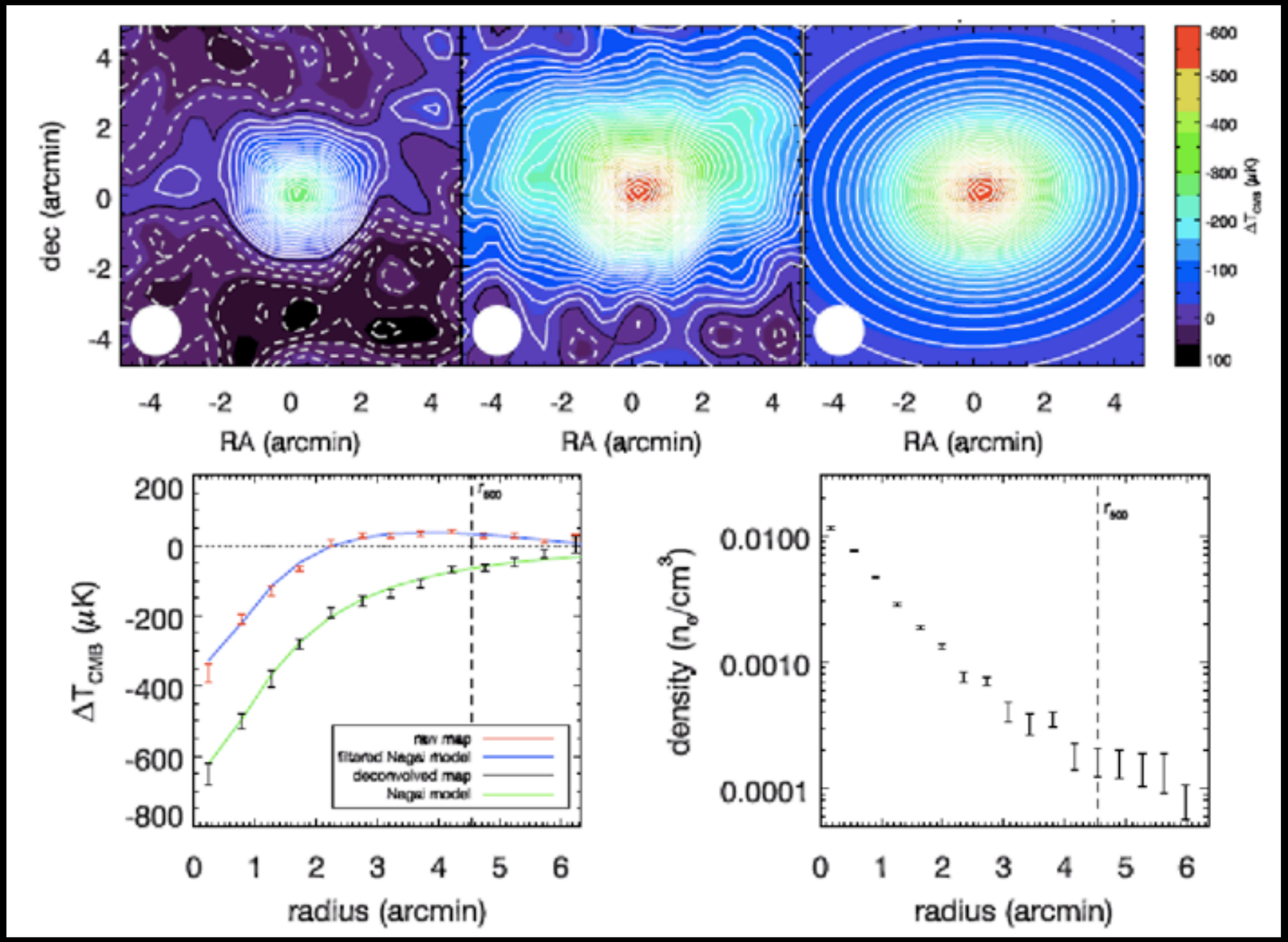
BVRIZ Subaru imaging for almost all CLASH clusters

That's not all



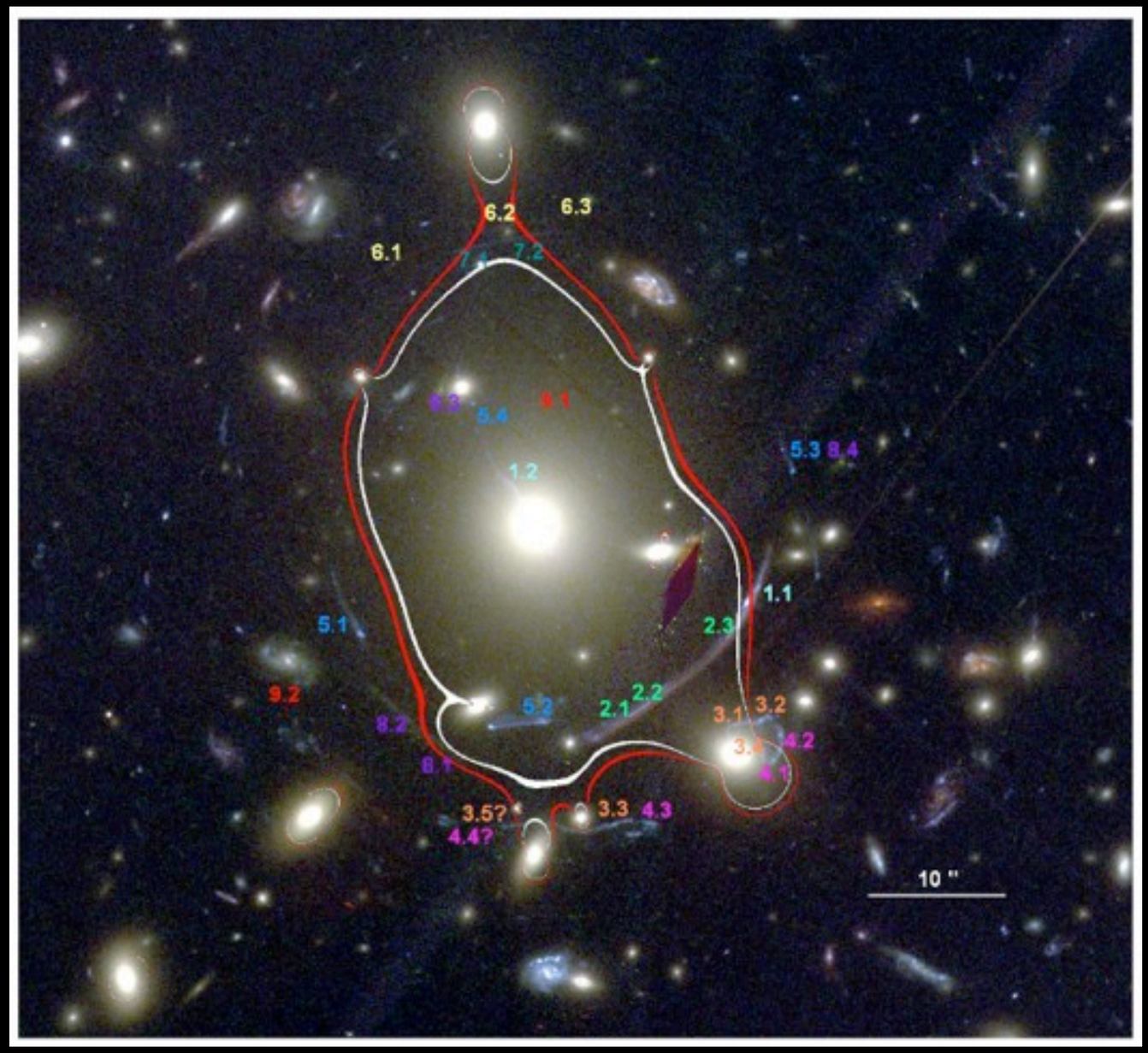
ULT/Magellan specs for arcs and cluster members

That's not all



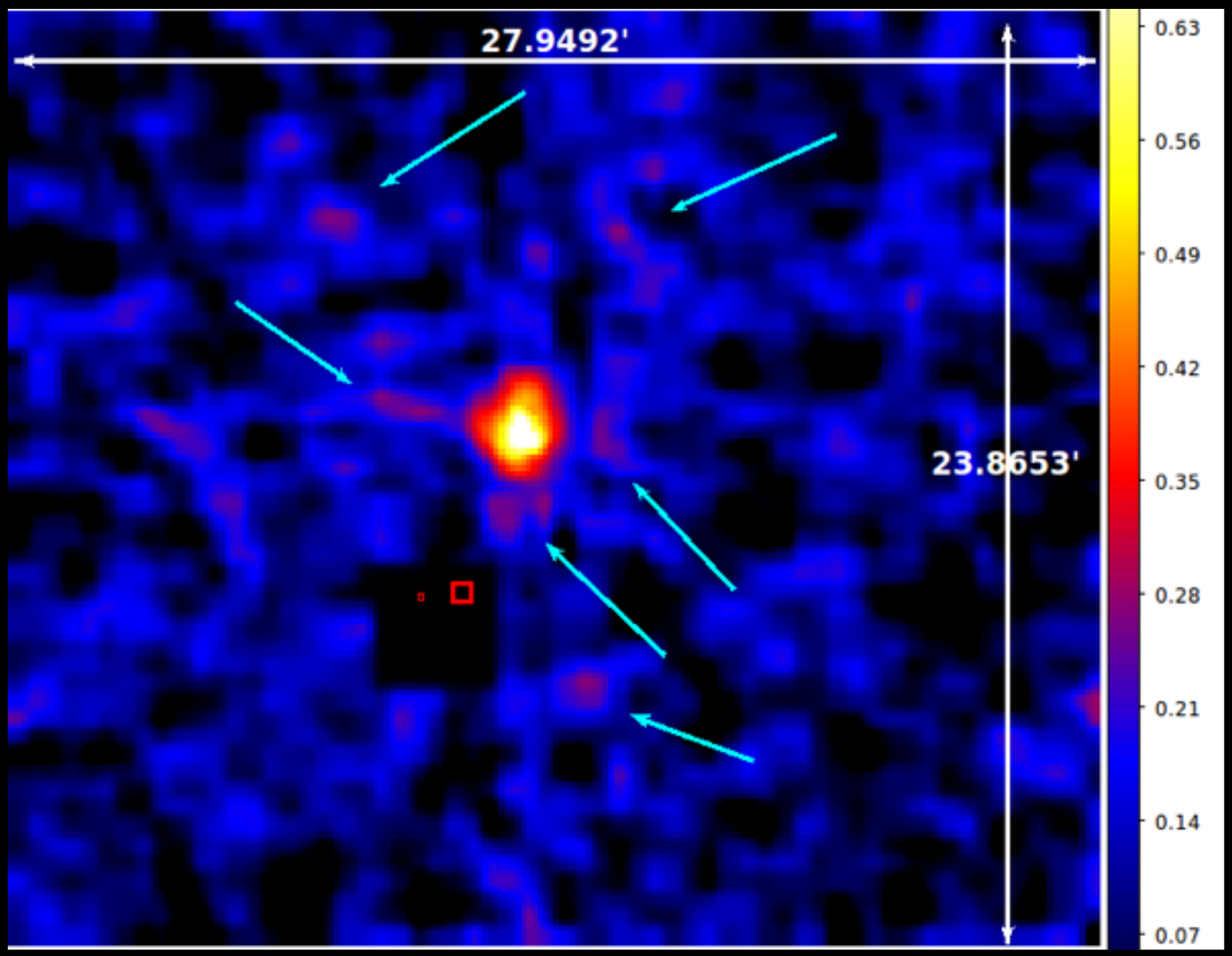
Bolocam / AMiBA / Mustang SZE observations

First results



The CLASH collaboration, some published some in prep.

First results



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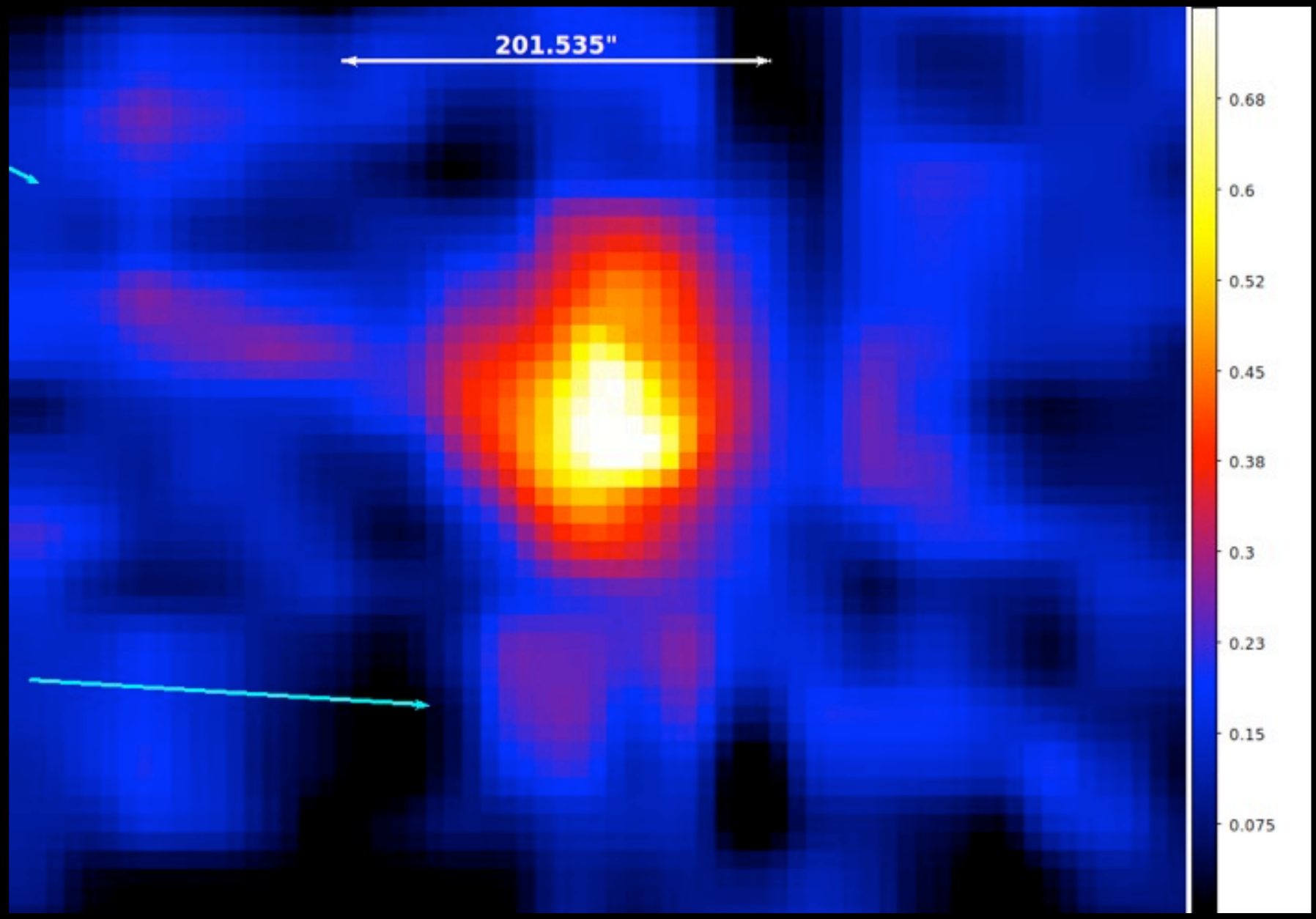

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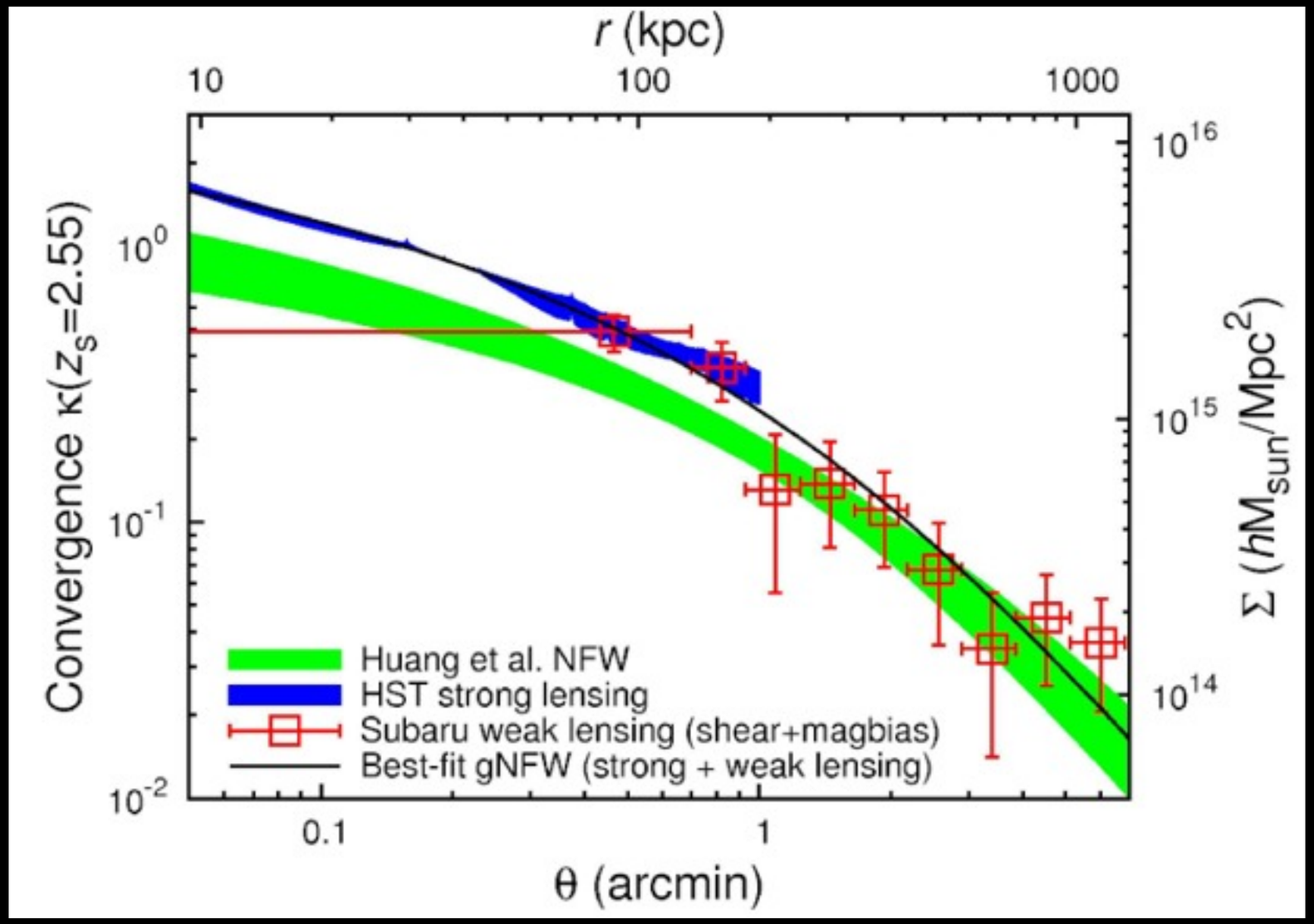

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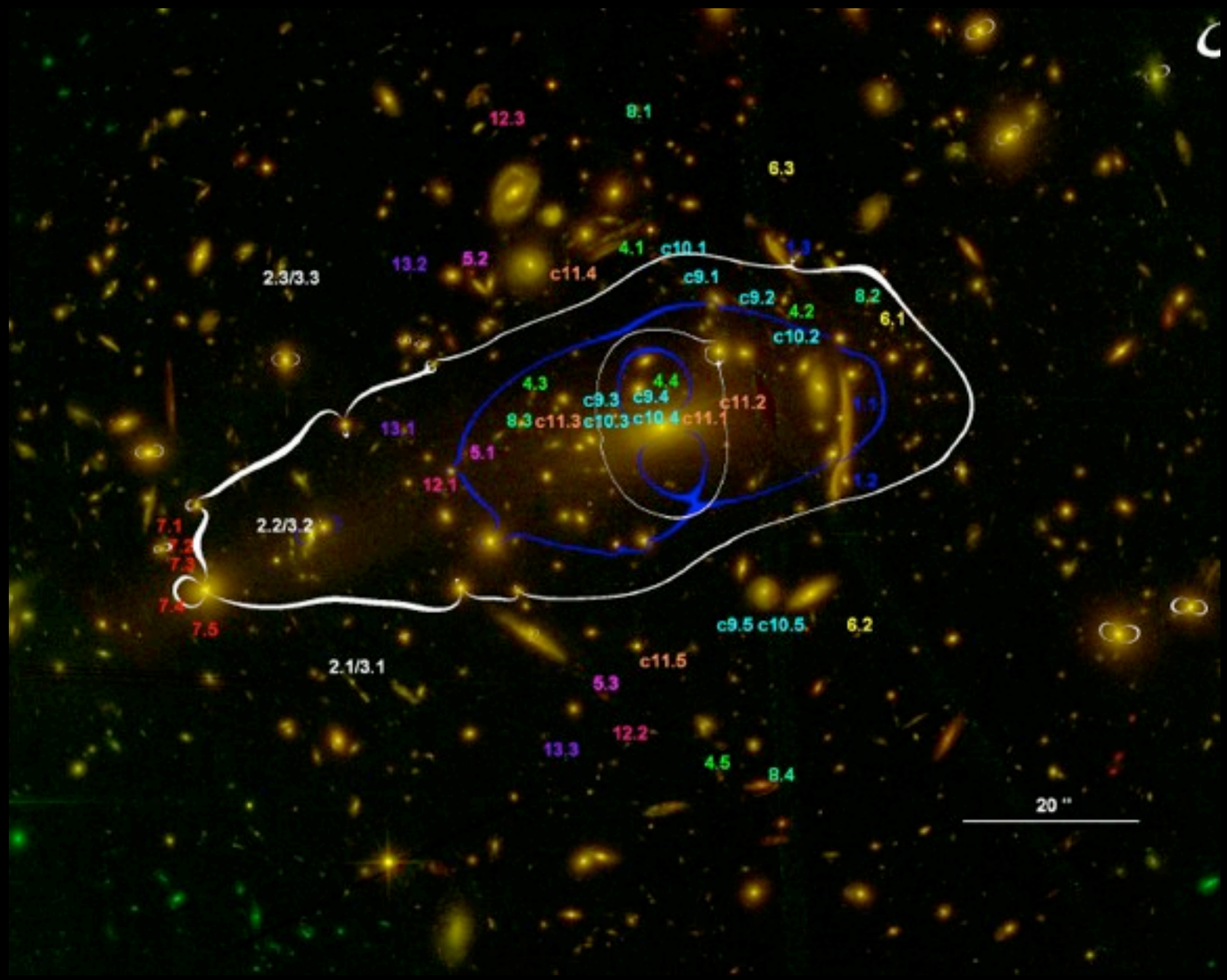

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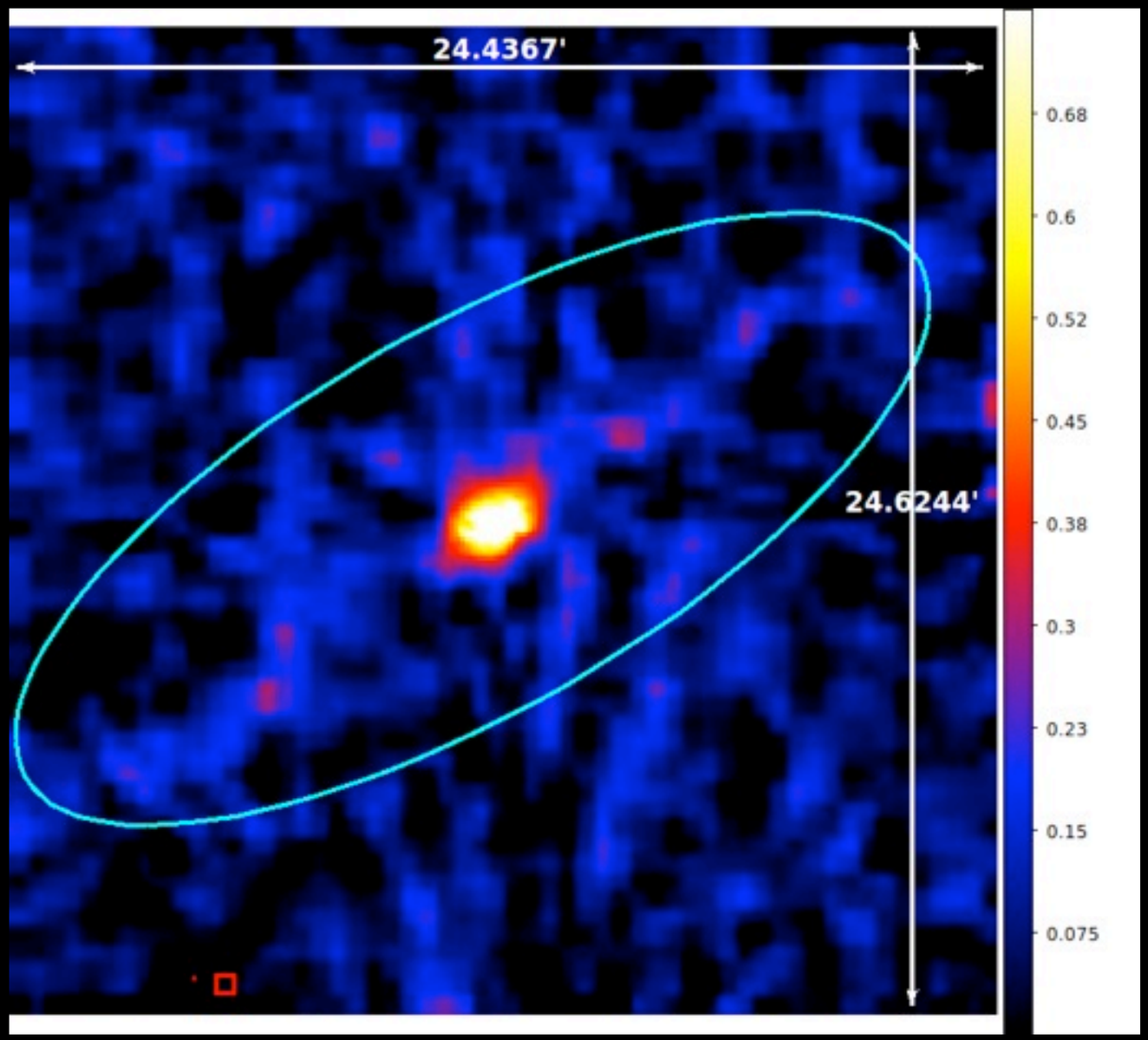

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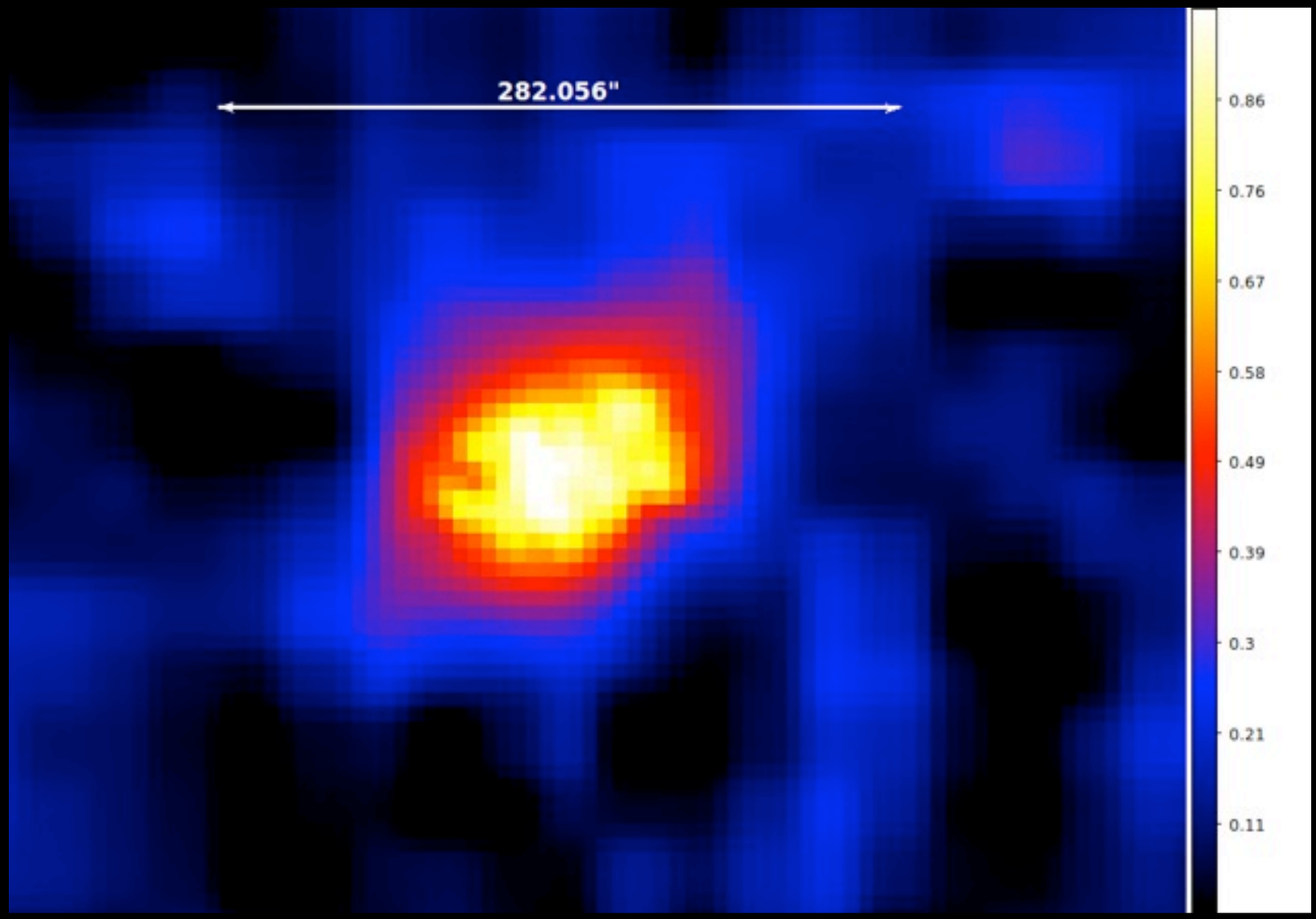

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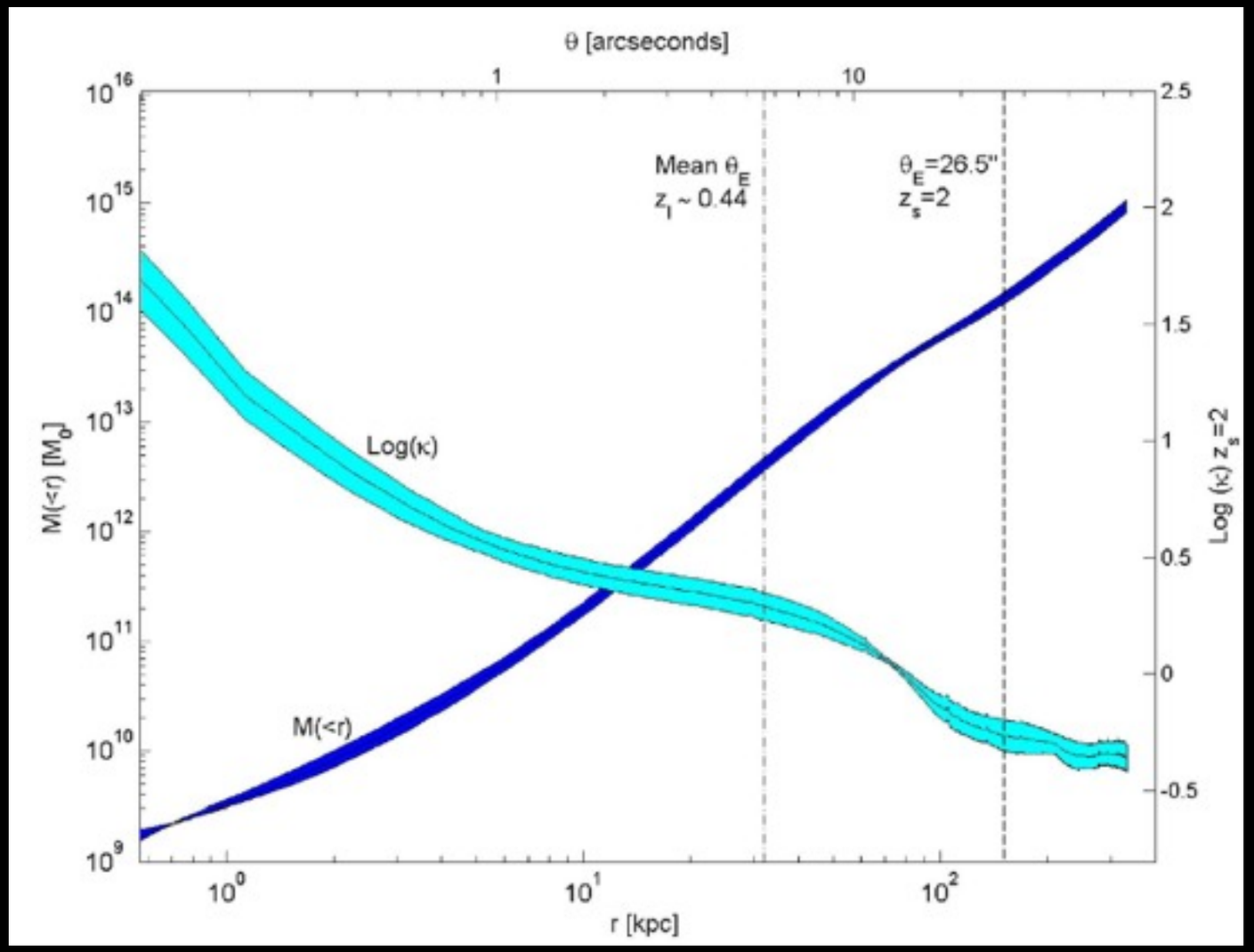

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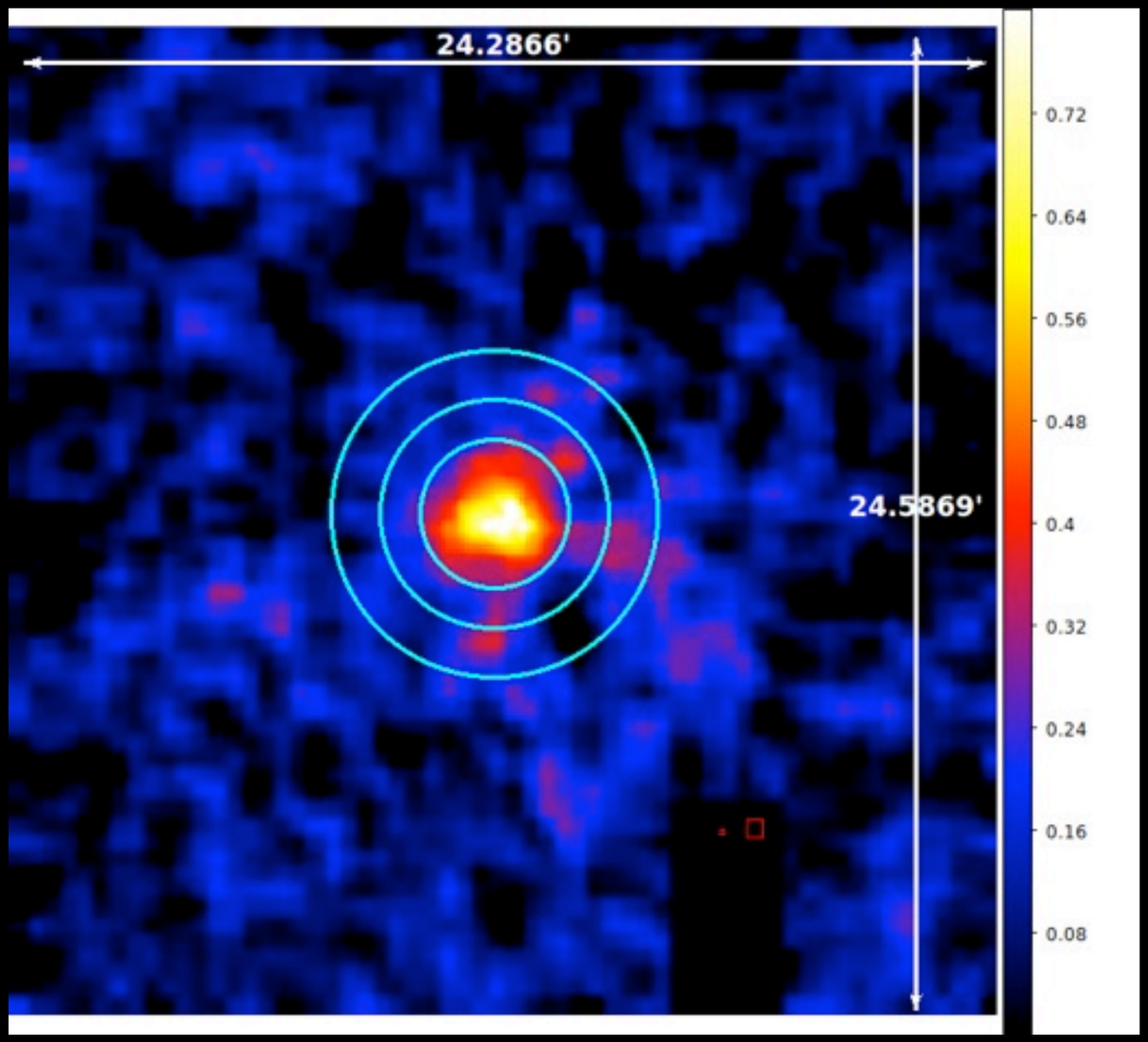

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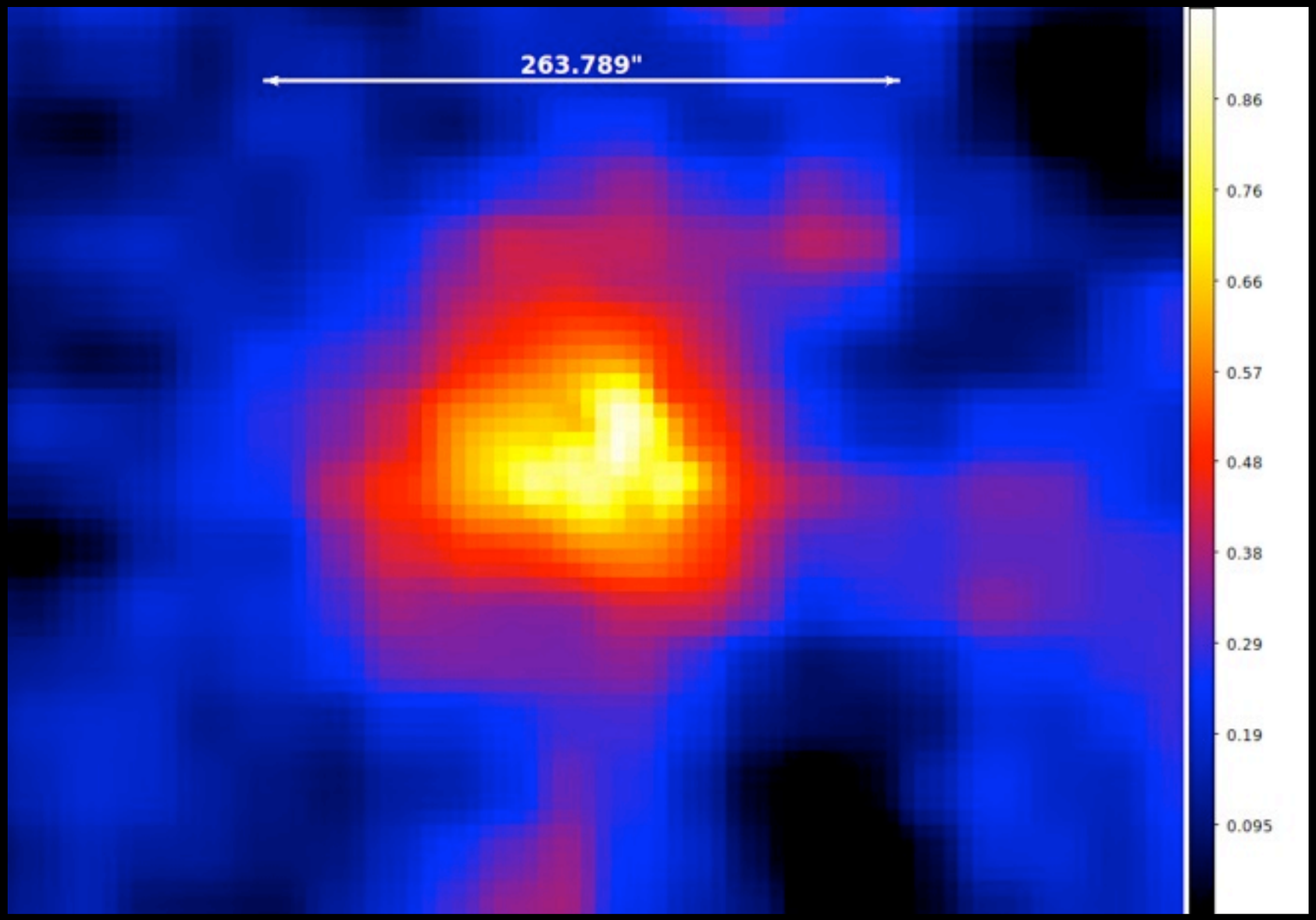
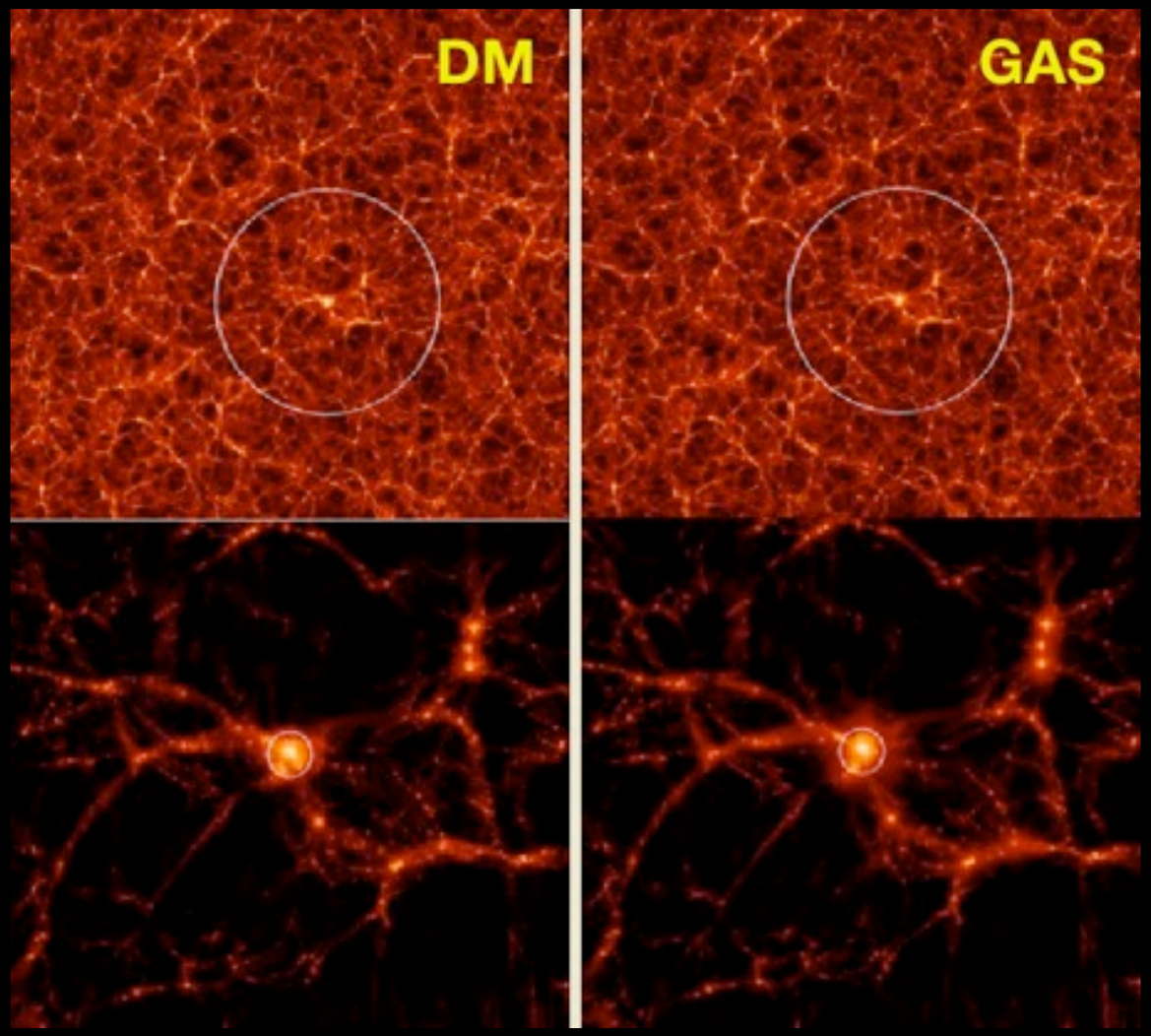


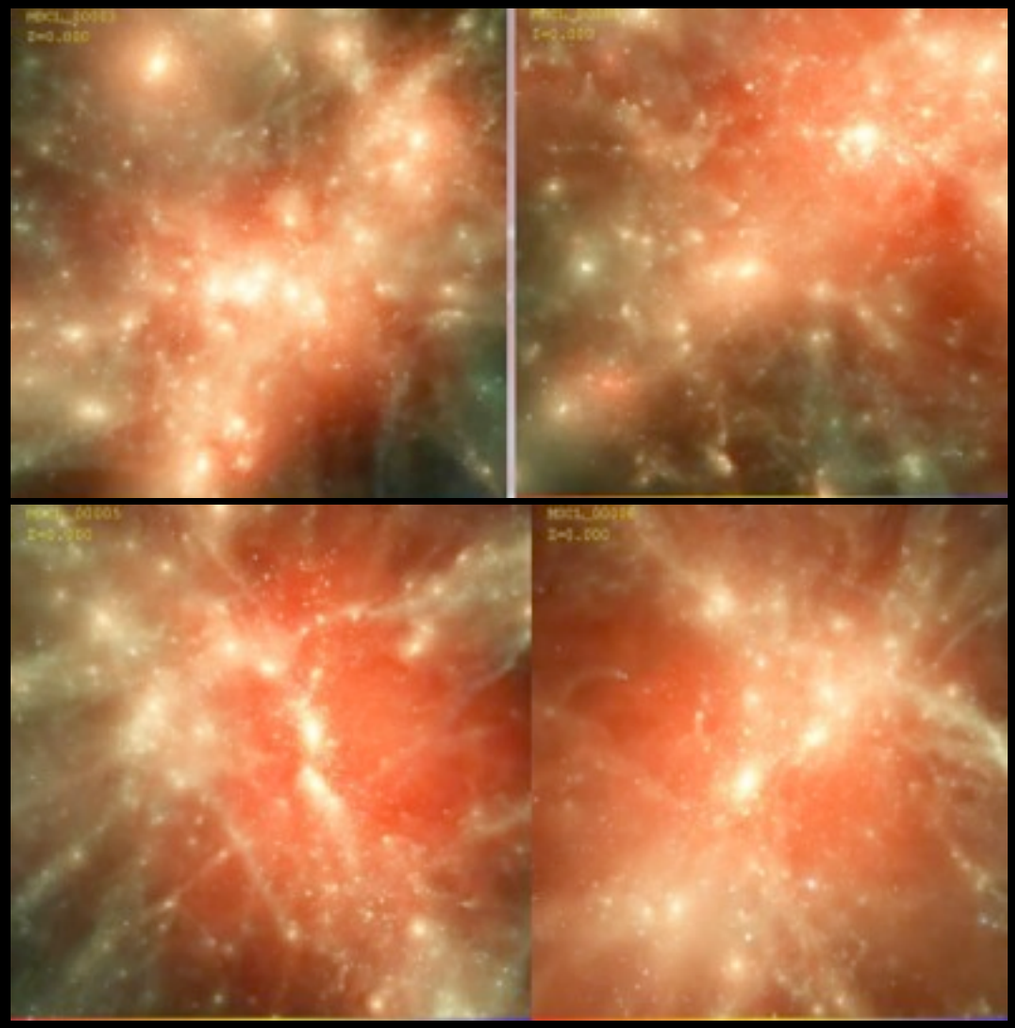
The CLASH collaboration, some published some in prep.

Simulations

Two kinds of simulations



big box, many clusters, few physics



small box, few clusters, more physics

Problems while comparing to simulations

- big boxes are usually DM only

  - high-res cluster sims deliver only small samples

    - impact of gas physics not completely clear yet

- not easy to compare apples and apples

Problems while comparing to simulations

– big b

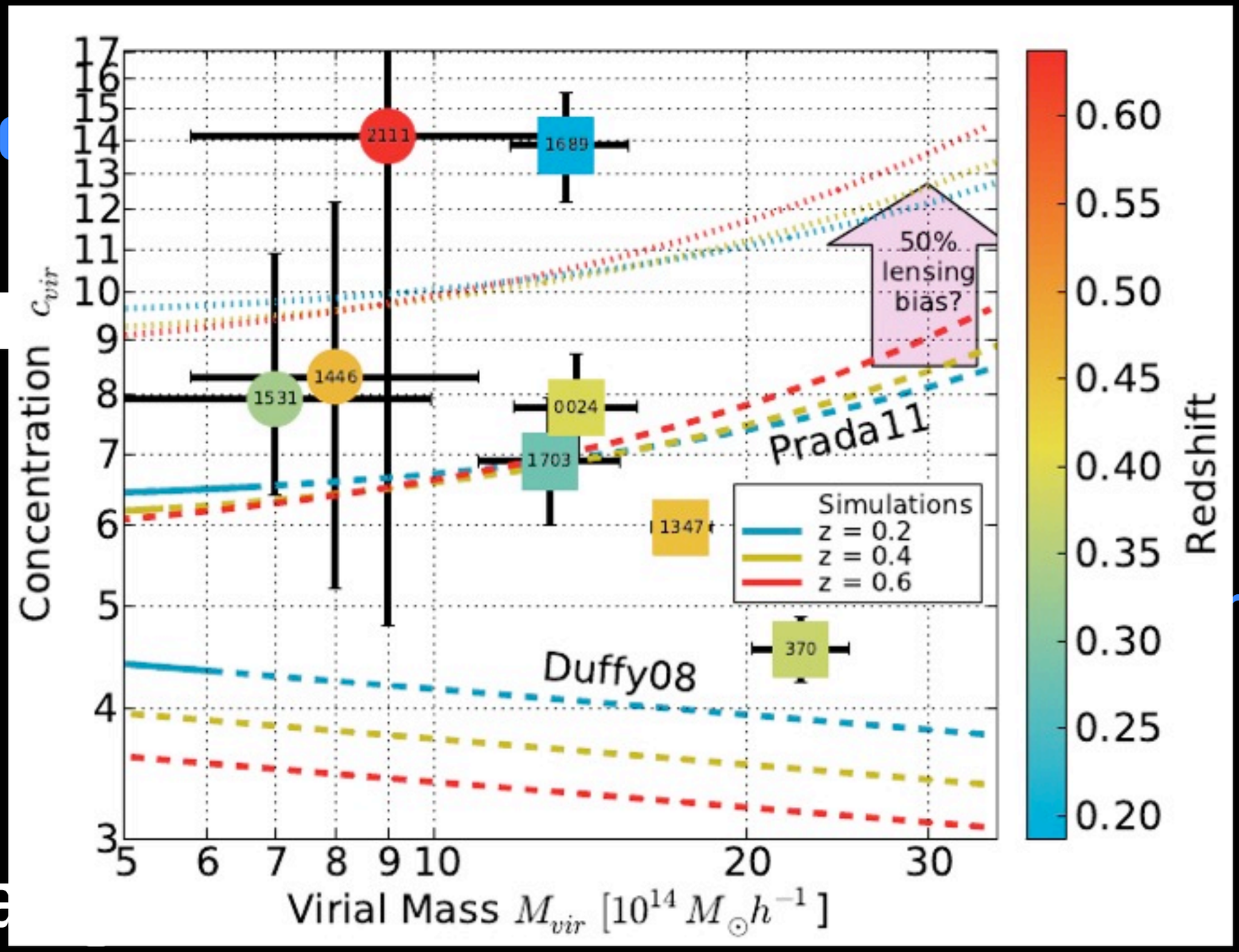
– hig

small

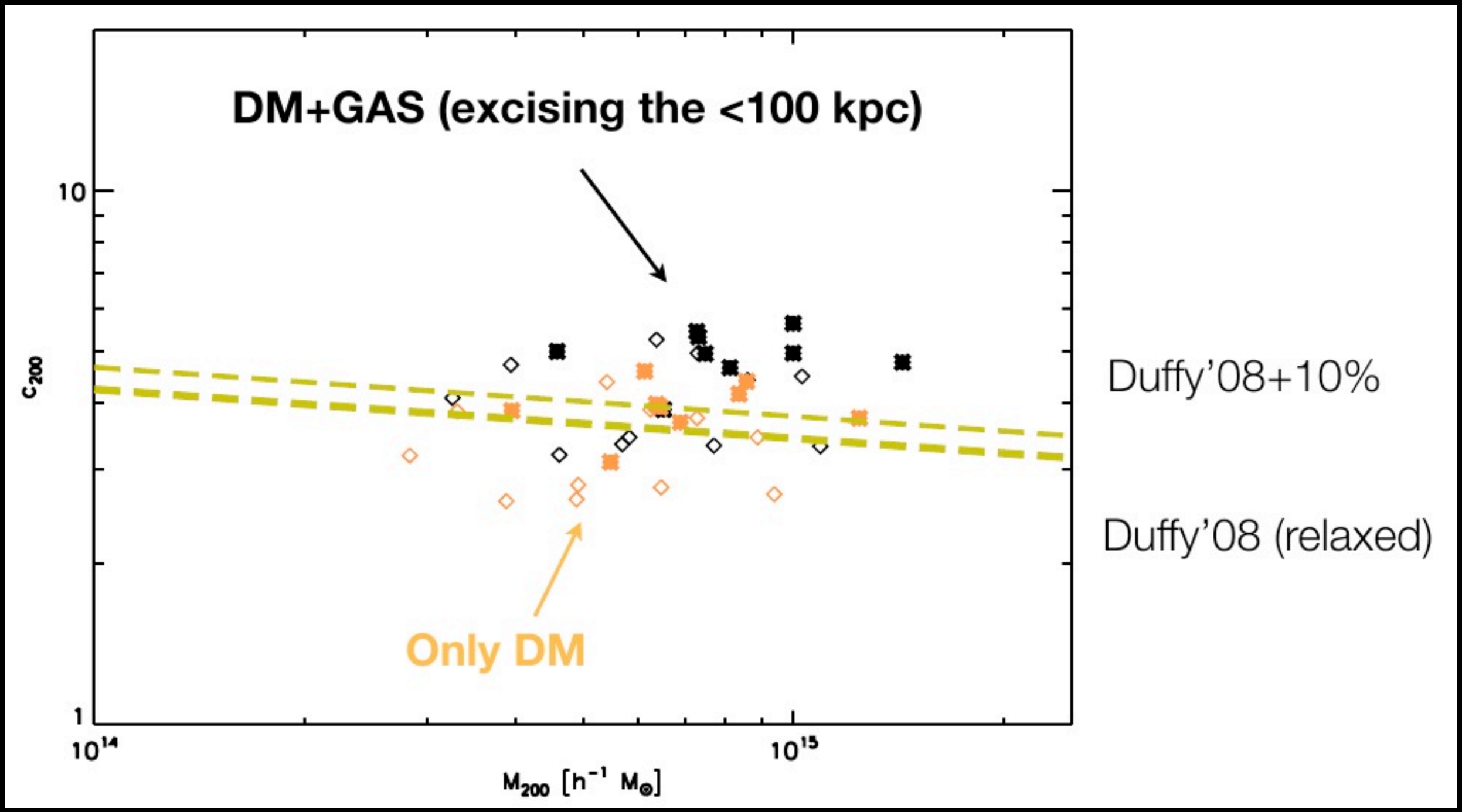
not

– not ea

apples

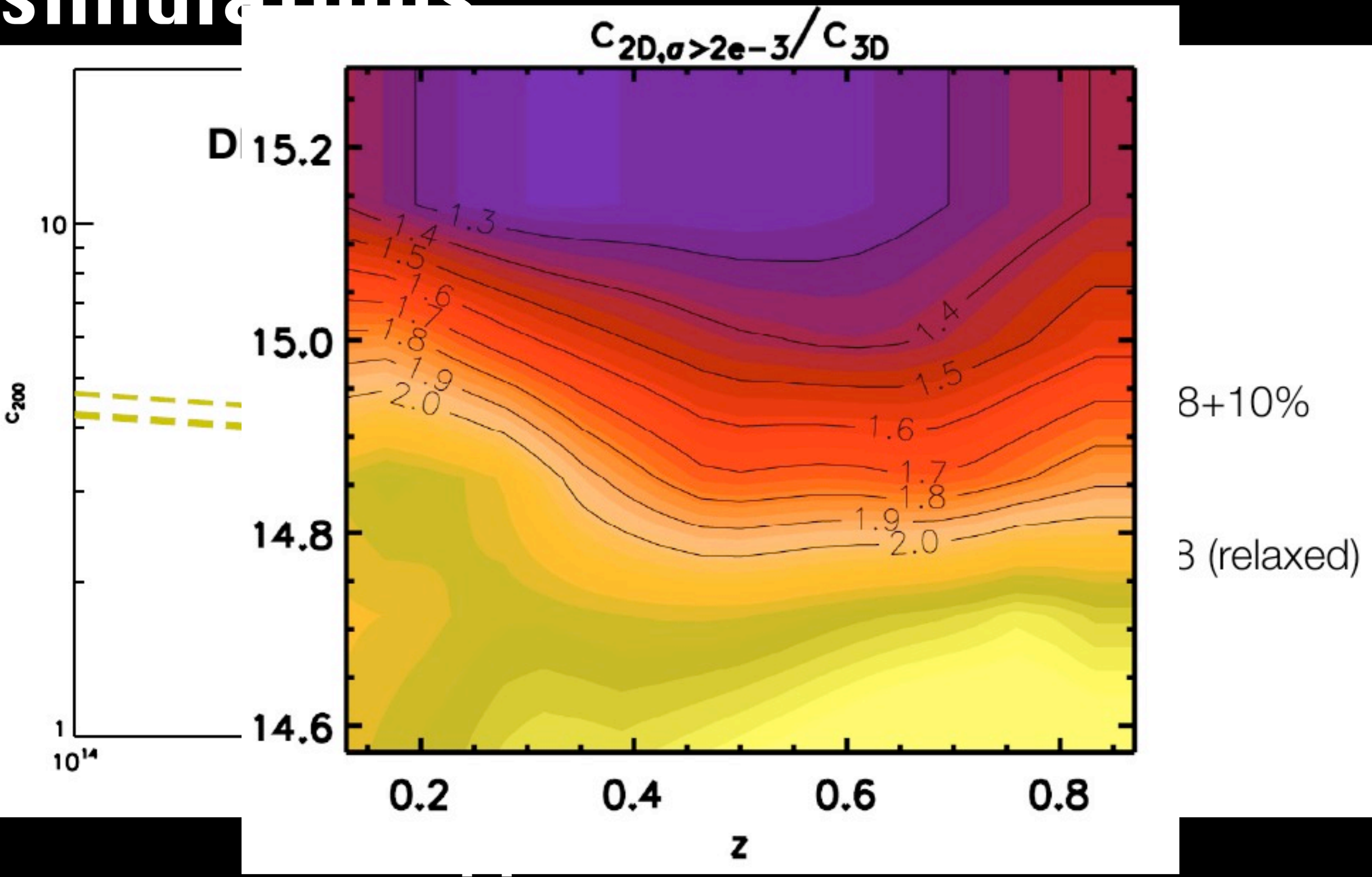


Problems while comparing to simulations



apples

Problems while comparing to simulations



8+10%

3 (relaxed)

Possible solutions

- Look into the simulations yourself, identify sensible quantities

- MultiDark, MXXL, DIANOGA, MUSIC

- Simulate an observation, pipeline is already available

Summary

Clusters are a good example for a cosmic laboratory

Multiwavelength, multiscale observations of clusters seem to lead on simulations right now

How to compare high-quality samples to simulations in an optimal way is not clear at the moment