WFIRST Science with Clusters of Galaxies

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AAS 2016

WFIRST benefits cluster science

- High resolution
- Large field of view
- Optical - infrared sensitivity to emission from stars
- Low sky background

What can be gained by increasing reliably-characterized samples with precision mass estimates from 10s to >1000s?

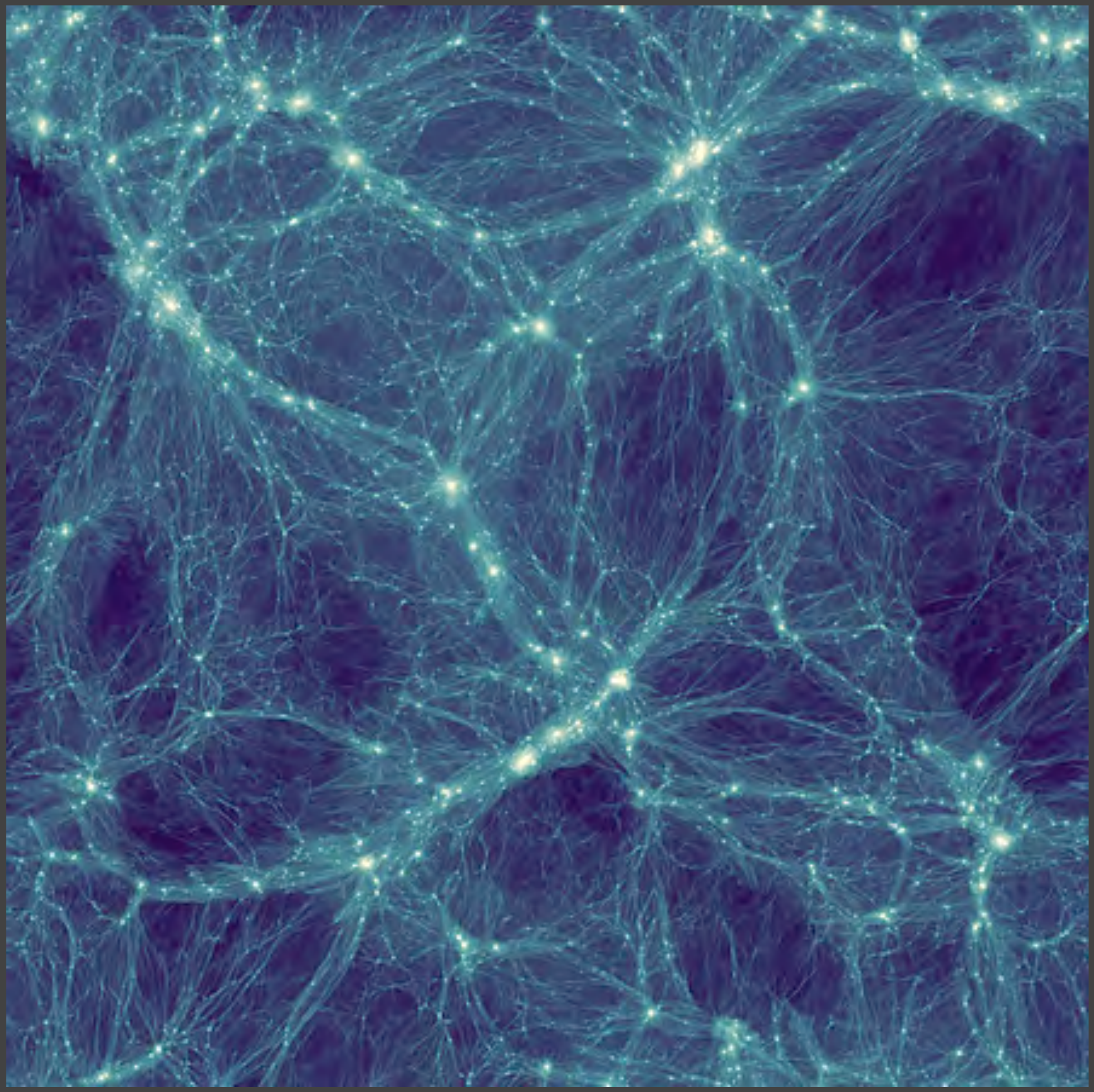
Features of clusters

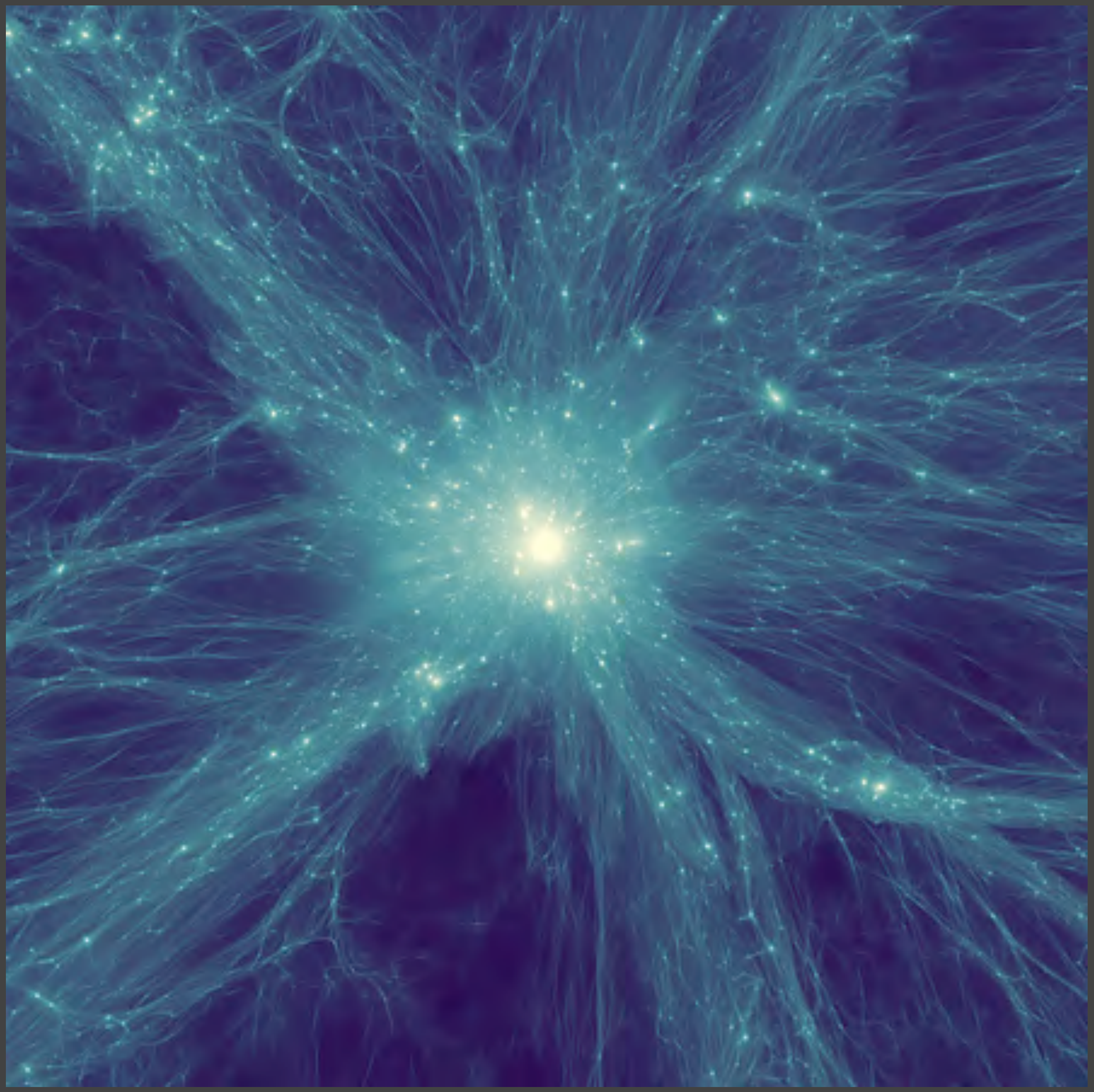
- Clusters are the most massive gravitationally-bound systems (up to ~10^{15} solar masses)
- Nearly representative census of matter (gas, stars, dark matter) within ~10 Mpc scales
- Intergalactic and circumgalactic gas accessible in emission and in absorption.
- Hosts the most massive galaxies and supermassive black holes.
- Natural laboratories for high-density galaxy environments with large numbers of galaxies (100s-1000s)

Massive Clusters are:
85% dark matter
13% gas
1-2% stars

Dark Matter, Simulated

Diemer & Kravtsov 2014





62.5 Mpc/h

15 Mpc/h

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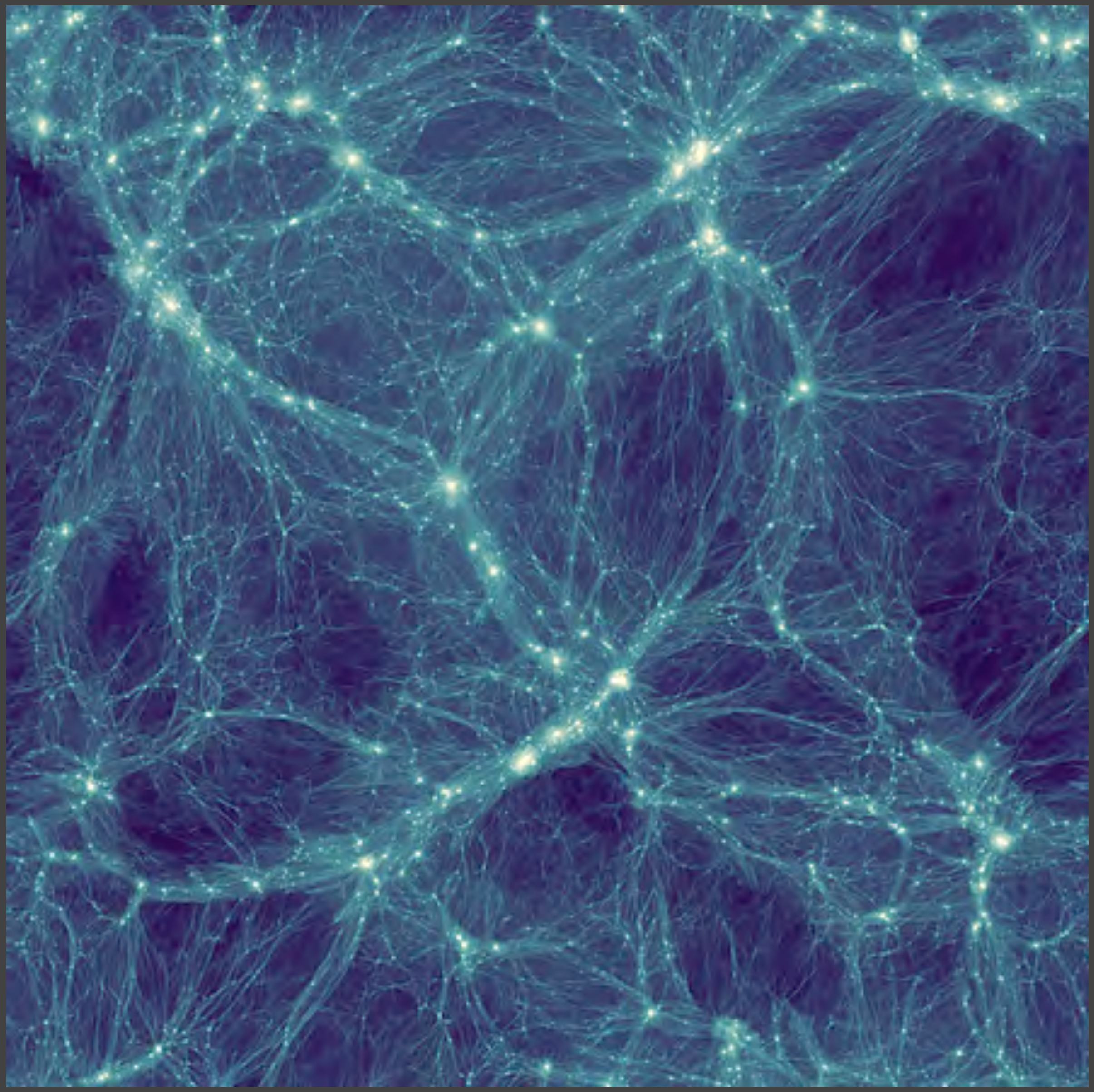

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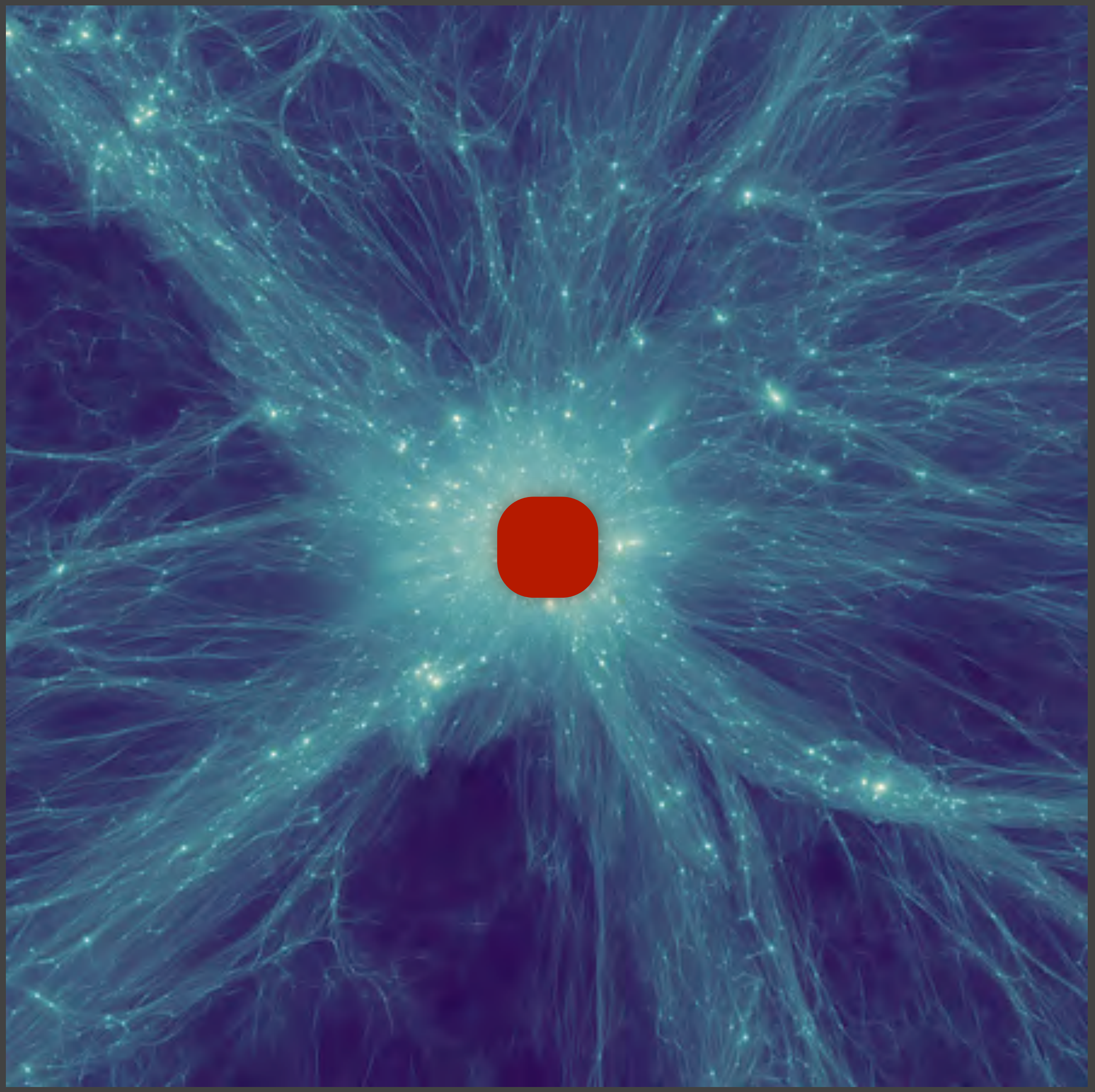
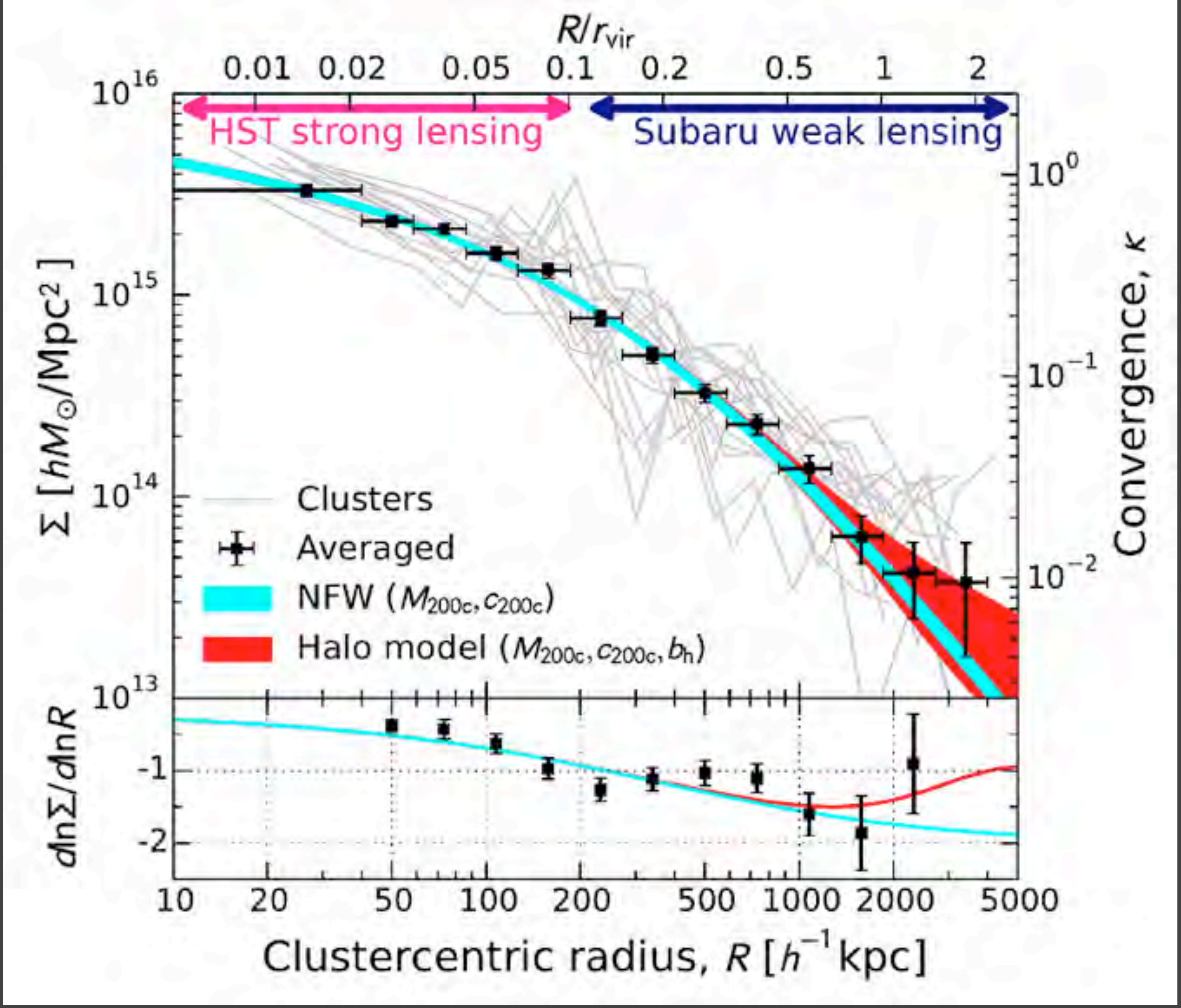


15 Mpc/h

CLASH Ensemble Mass Profile



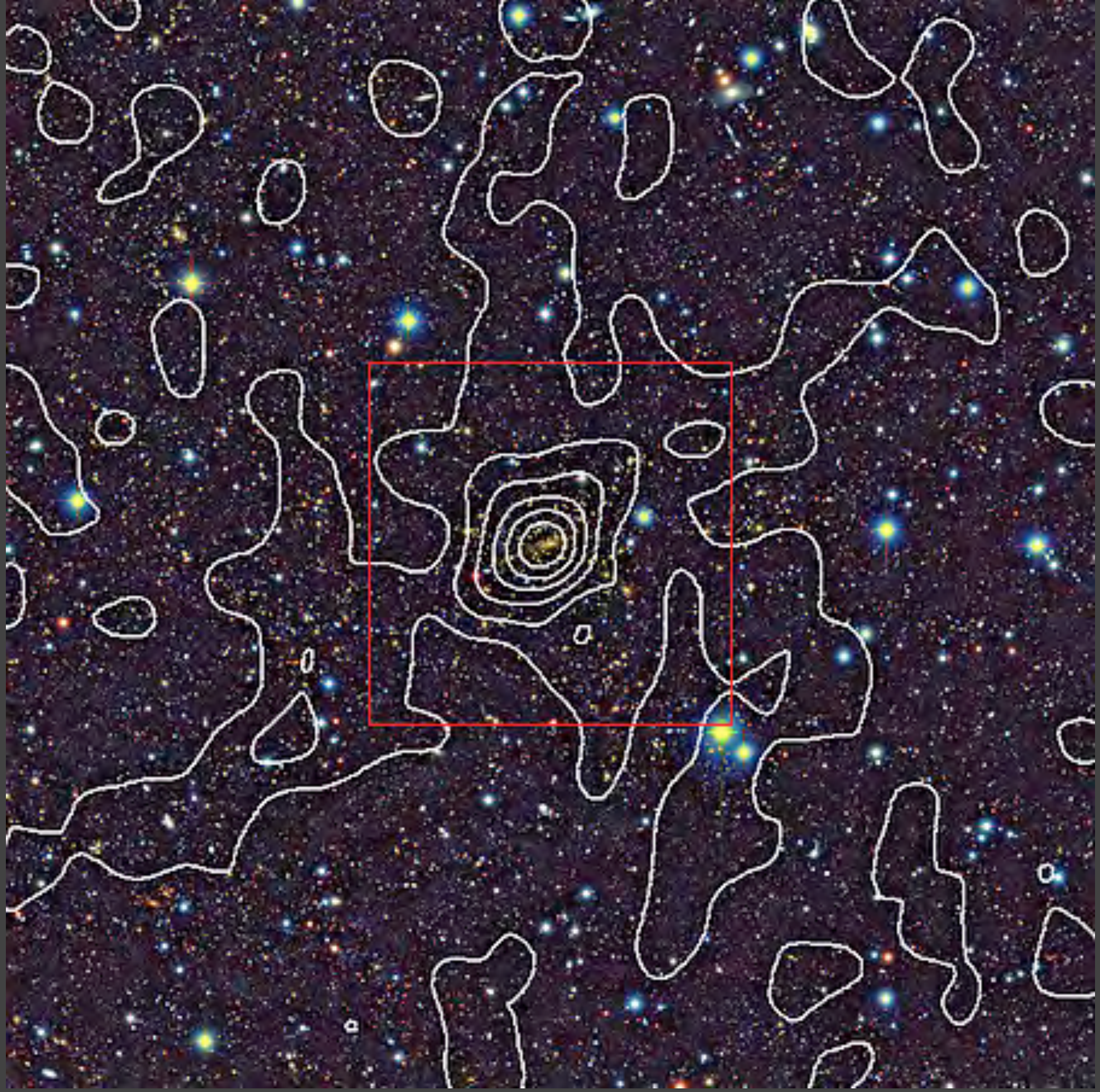
Umetsu+2015

Wide-field imaging allows HST-level PSF and galaxy densities over arcminute scales

Subaru

HST

MACSJ1206.2-0847 z=0.44



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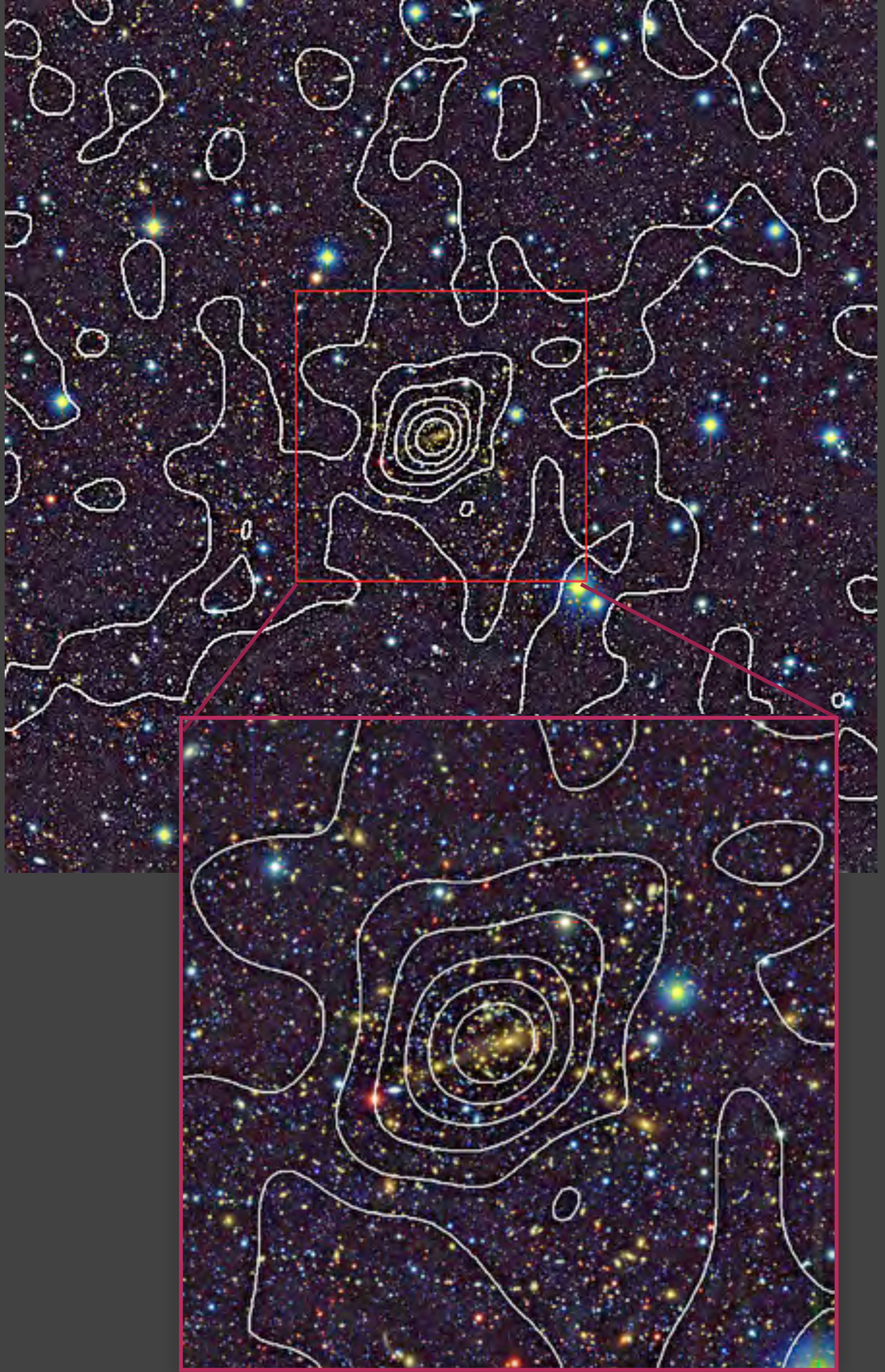

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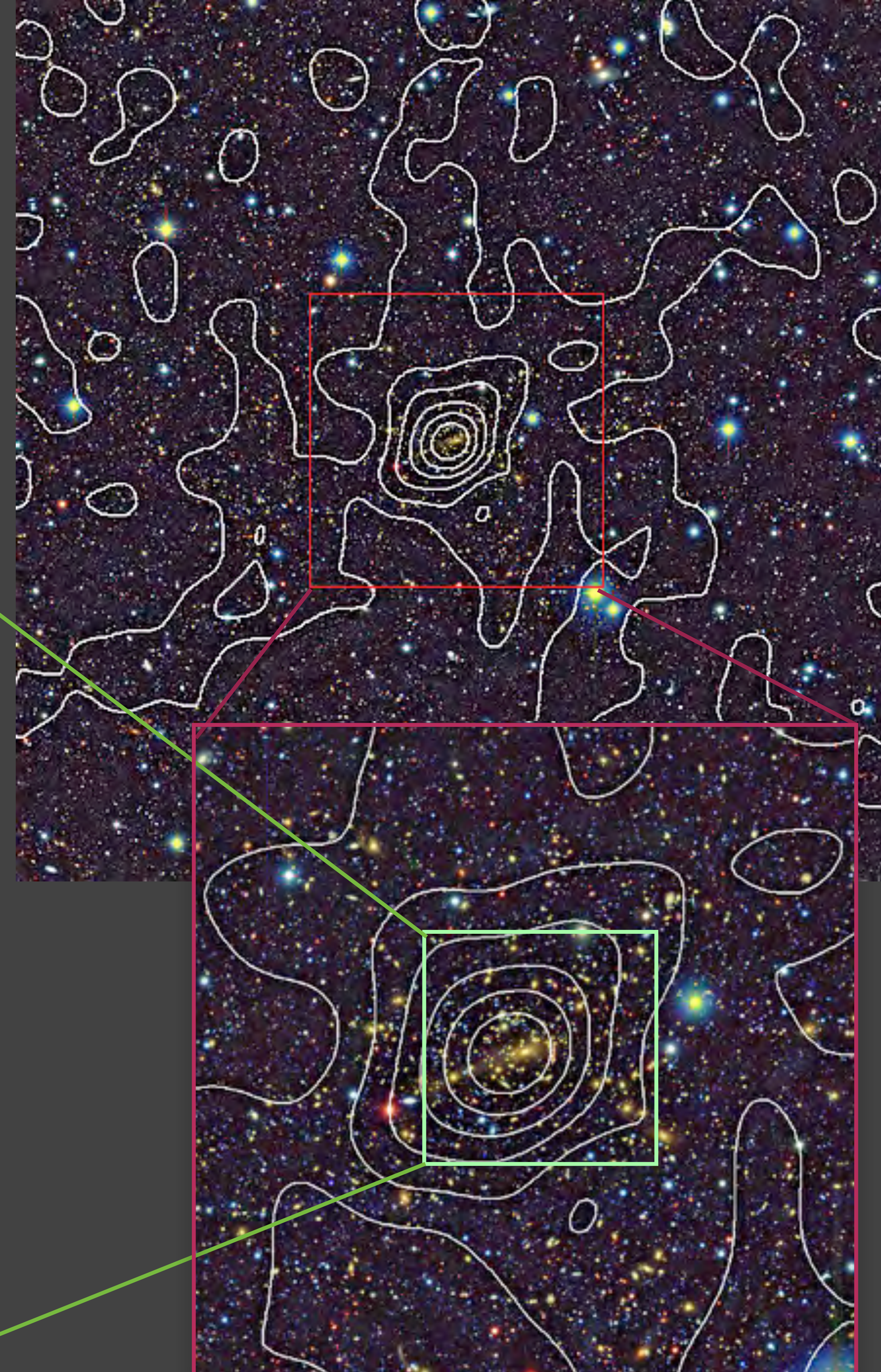

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WFIRST FOV

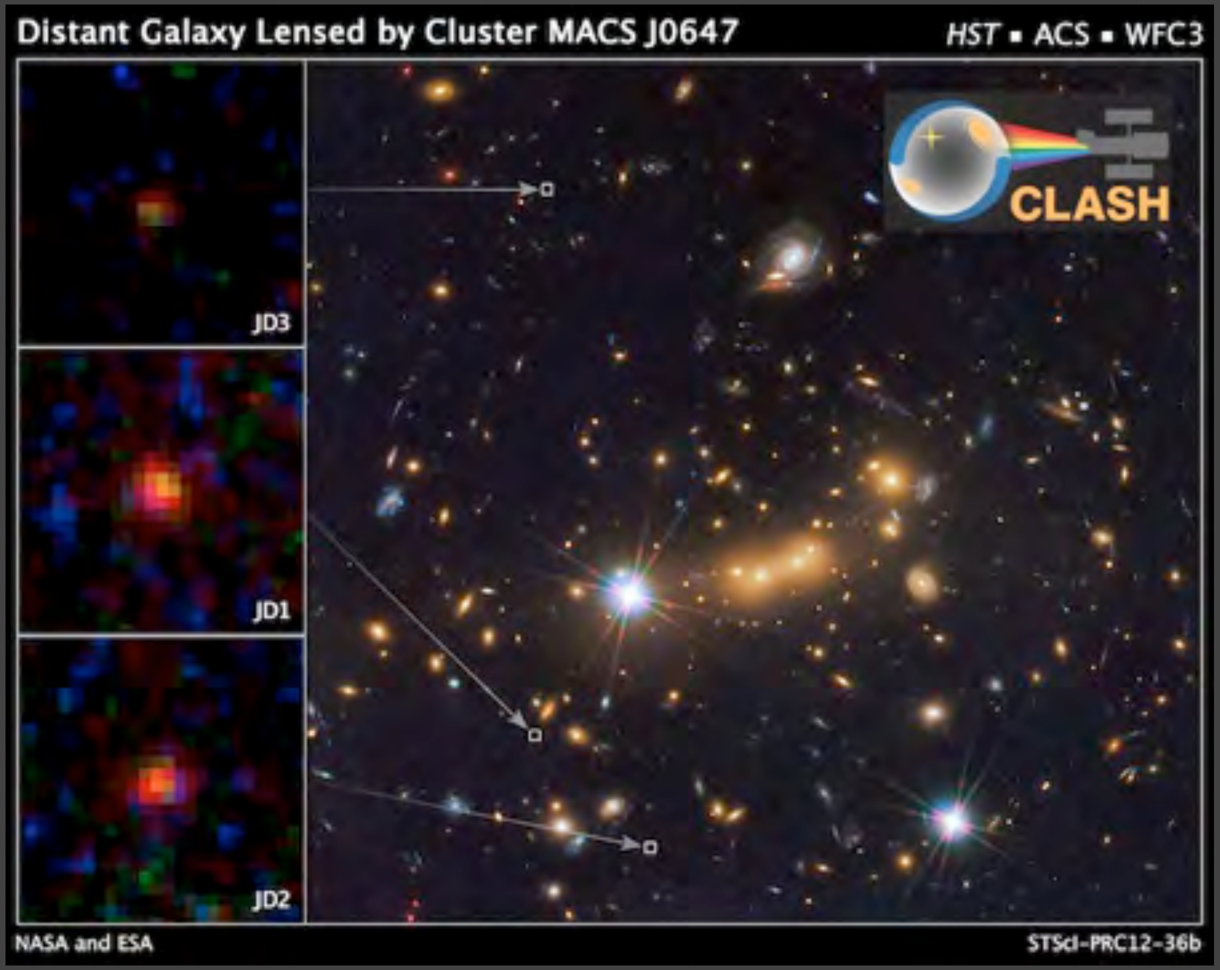
Umetsu+2012

Legacy of HST-CLASH and HST Frontier Fields

- Software and modeling tools for analyzing weak and strong-lensing data (SaWLenS, Lenstool, WSLAP+, also codes from Zitrin+2015, Umetsu+2011)
- Value of X-ray, SZE, and galaxy kinematics (velocity dispersion, caustics)
- Shared data, tools, and derived products (magnification maps, selection volume estimates, etc.)

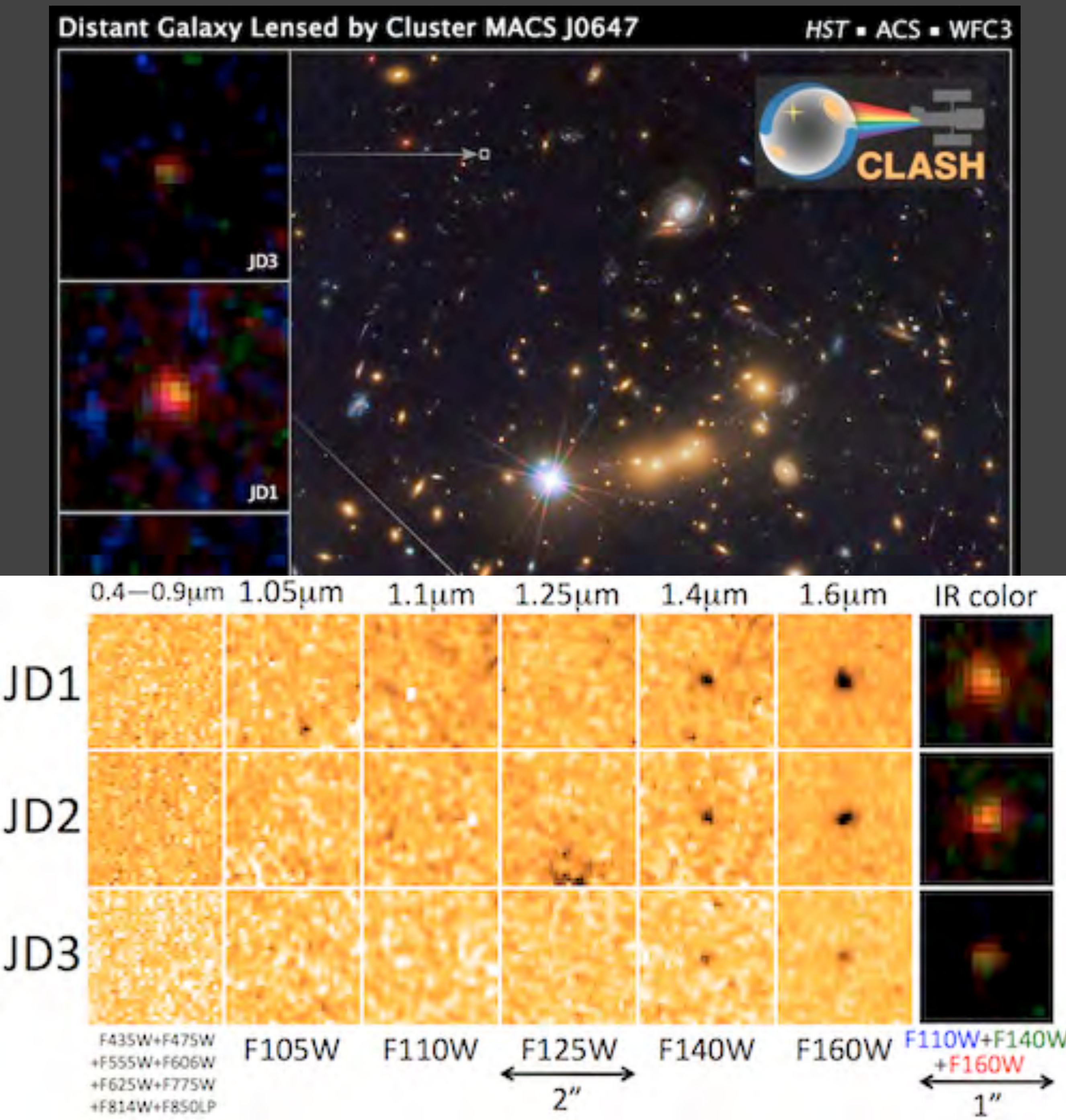
Magnifying the high-redshift universe

Coe+2012



Magnifying the high-redshift universe

Coe+2012



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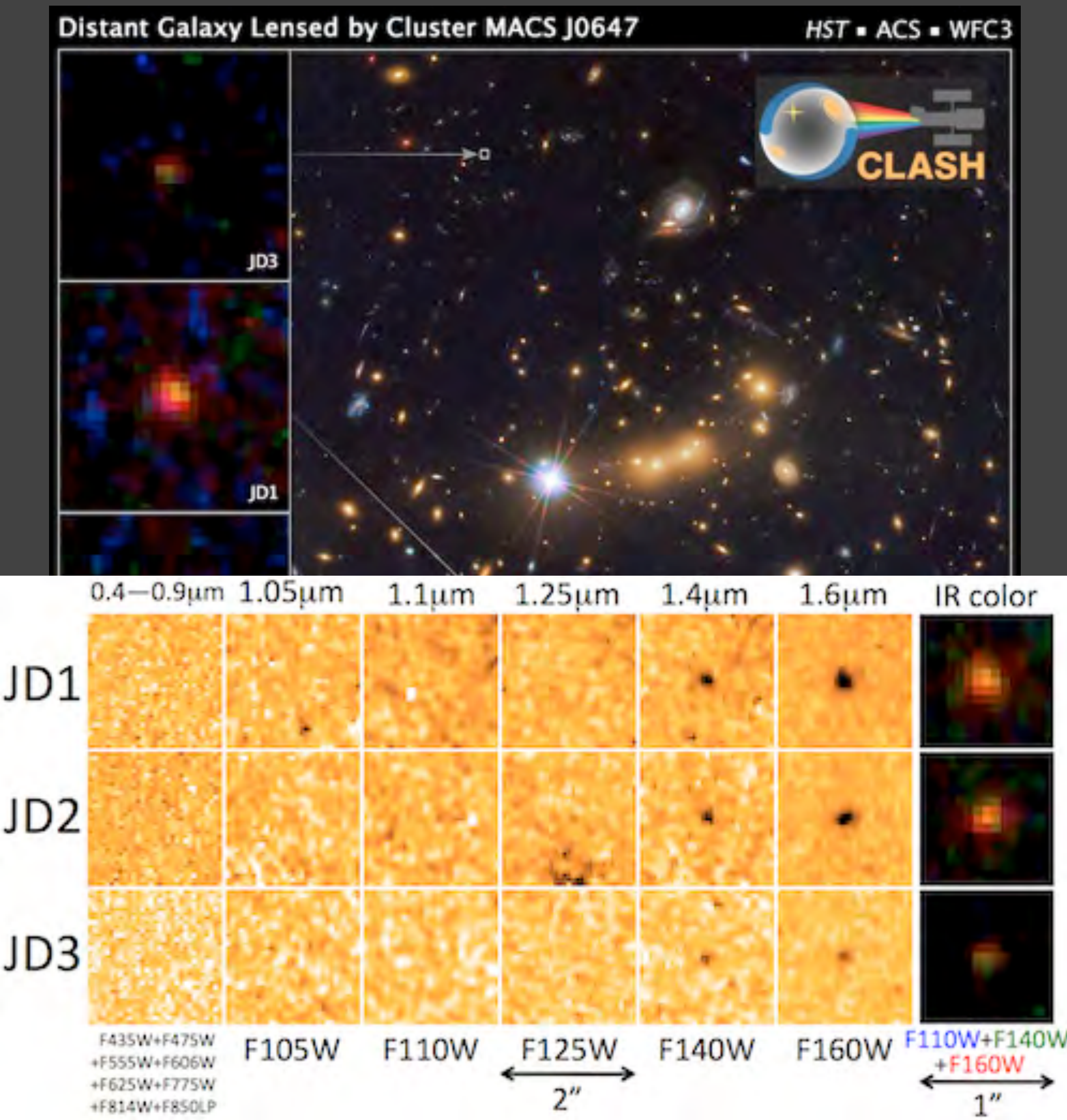
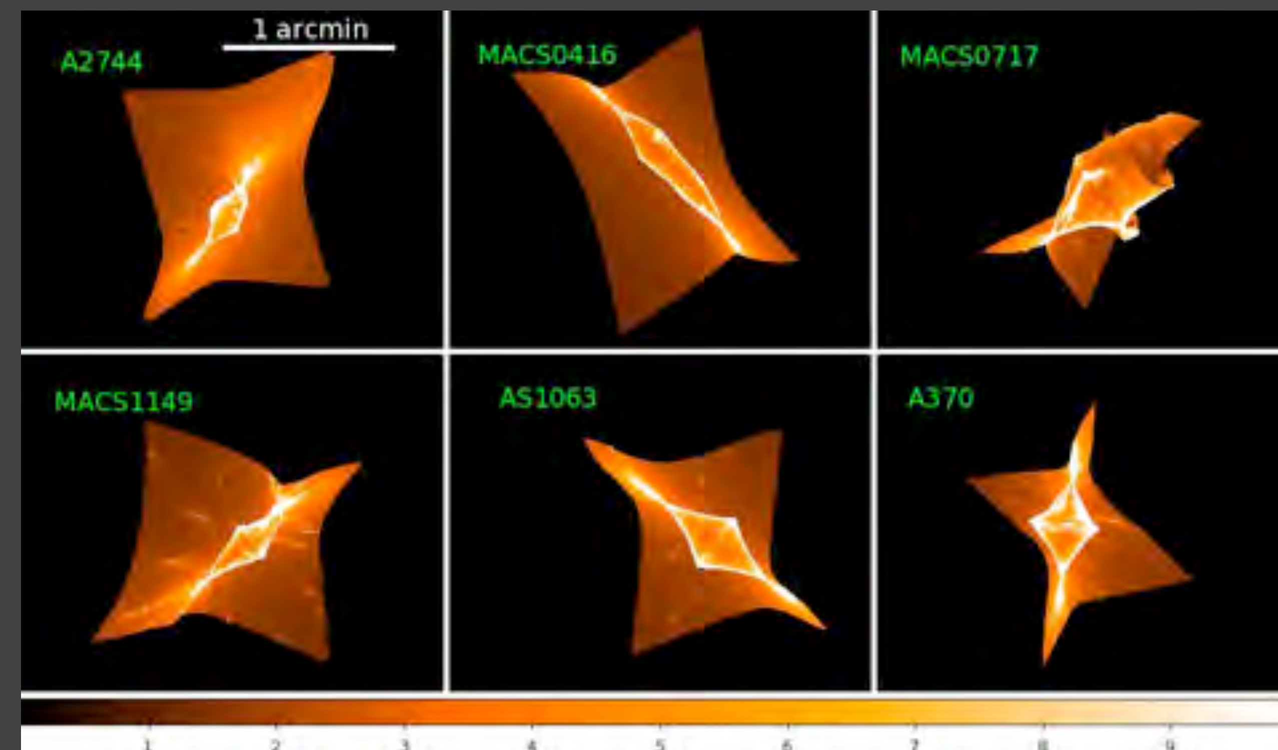


Richard+2014



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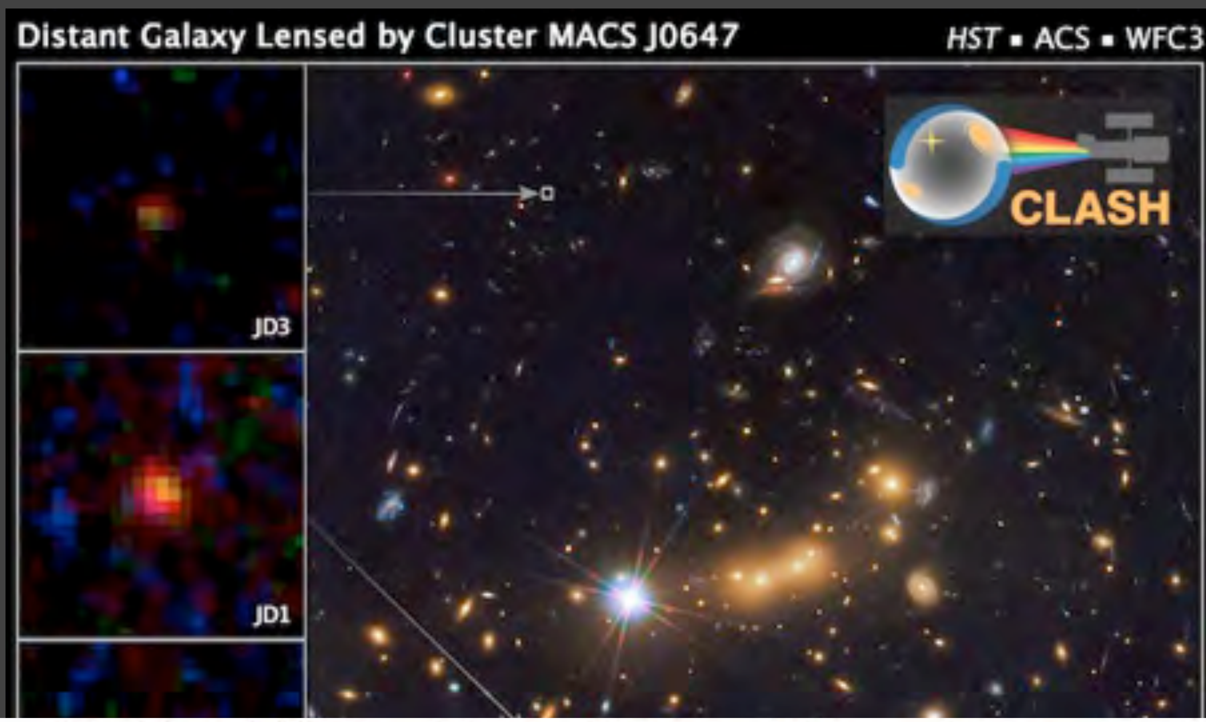
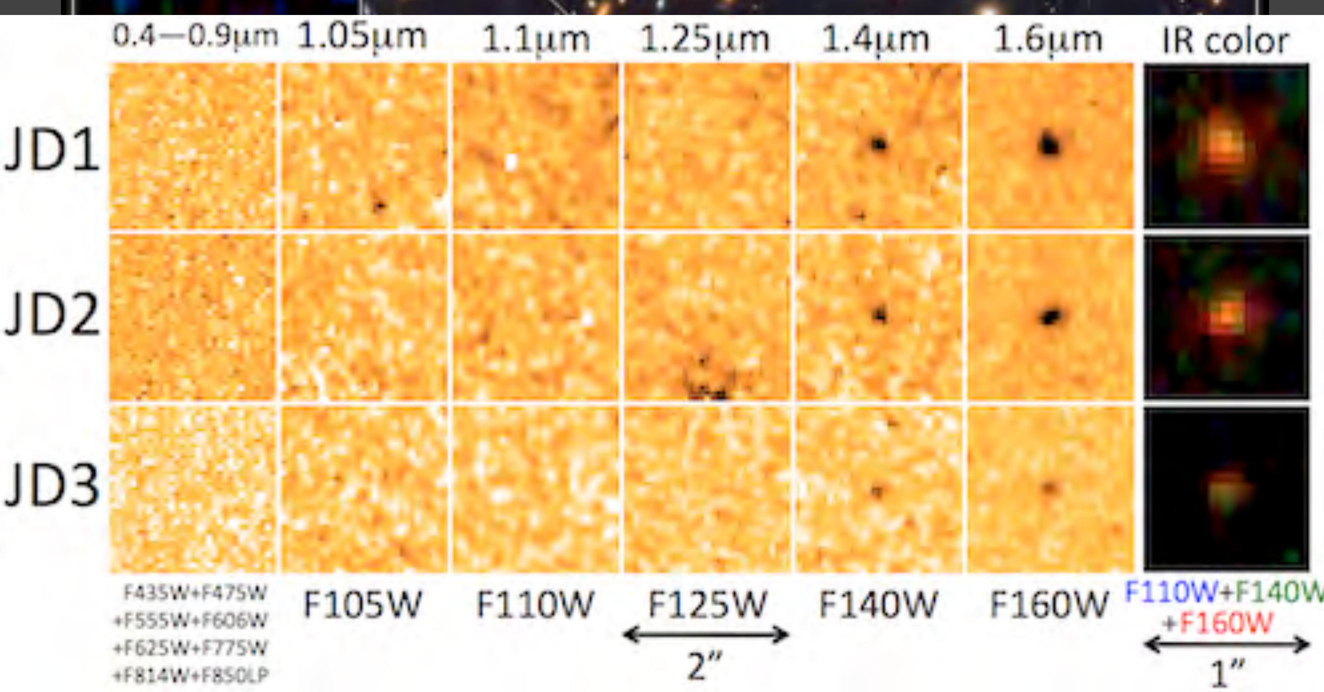




Lensing with WFIRST

- Cluster lensing causes shear, deflection, and magnification of background galaxies.
- Combining weak-shear, magnification, and strong-lensing mitigates the mass-sheet degeneracy.
- WFIRST will measure total gravitational masses, mass radial profiles, 2-d mass structures around clusters and galaxies with resolution unfeasible from the ground.
- $M(R>R_{vir})$ and large-scale filaments will be characterized.

Galaxy density

- Resolution in lensing is limited by numbers of galaxies for which a shear measurement can be made.
- The High-Latitude Survey density: ~75 galaxies per square arcminute in co-added J & H bands
- Targeted GO observations could achieve 200-300 galaxies per sq. arcmin.

empirical scaling laws

Example of Cluster M-Tx

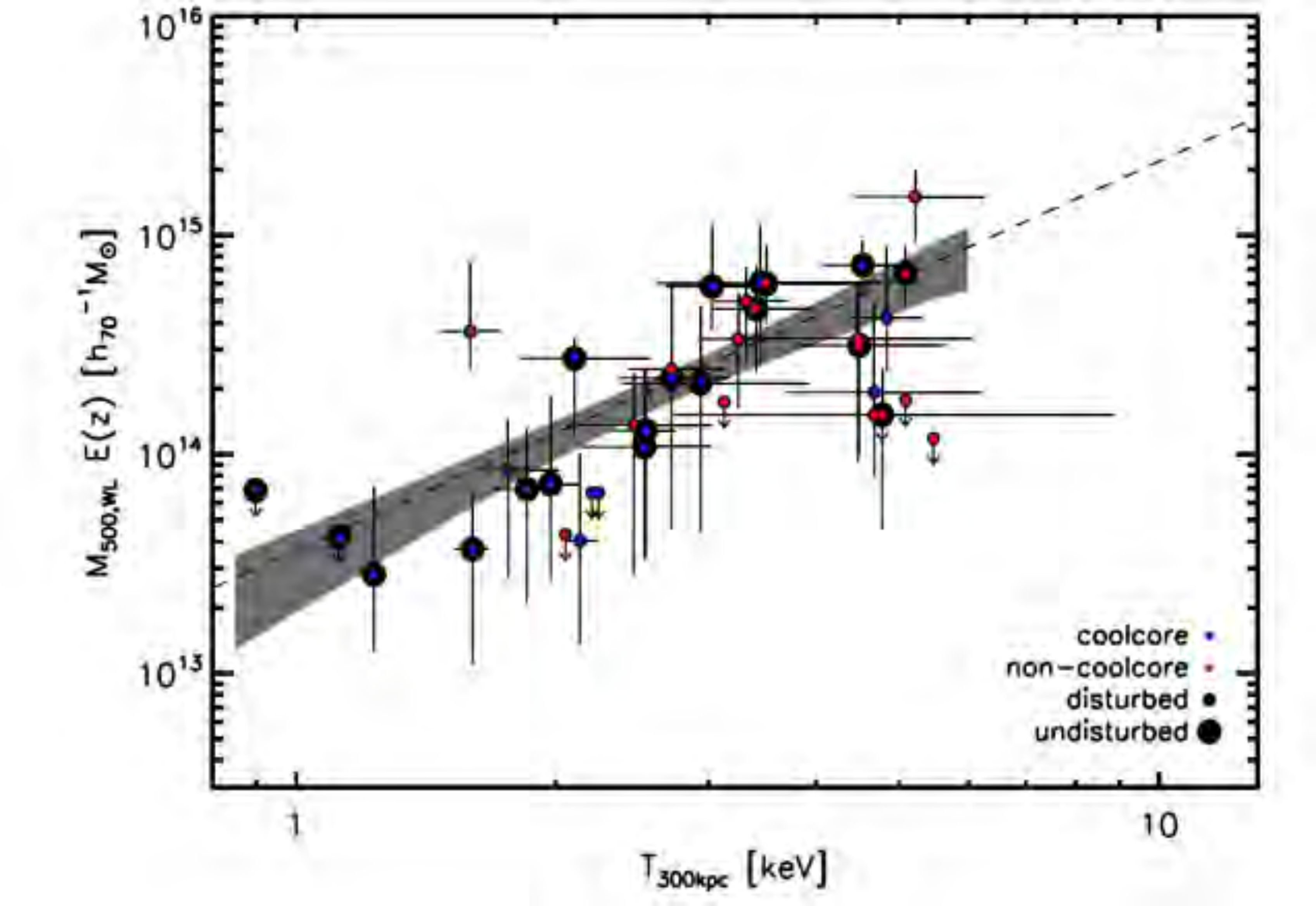
Lieu+2015

38 clusters from XMM LSS survey + CFHTLens

Core included

mass-concentration assumed

self similarity predicts $M \sim T^{3/2}$



Example of Cluster M-Tx

+20 CLASH clusters
Lieu+2015

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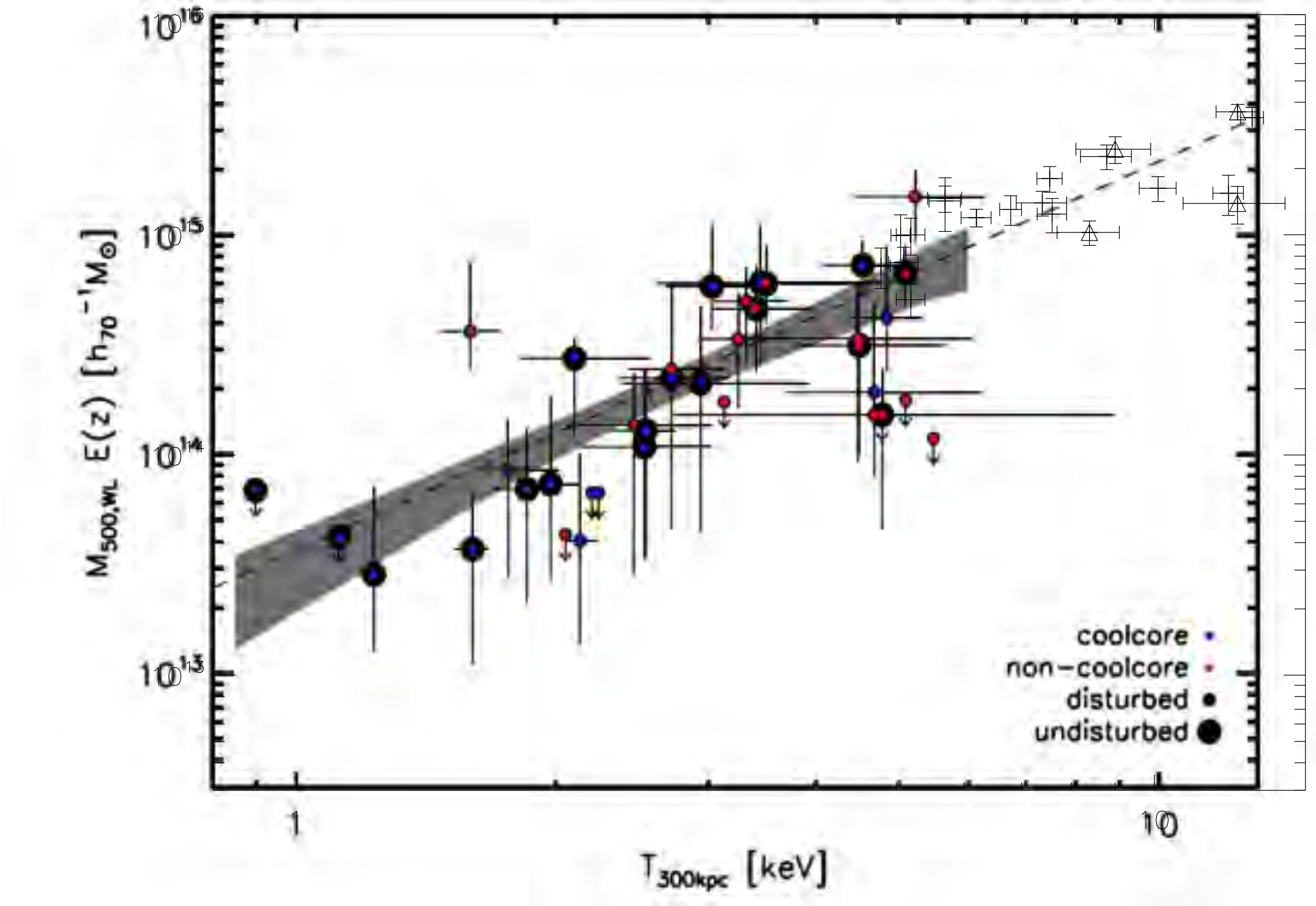
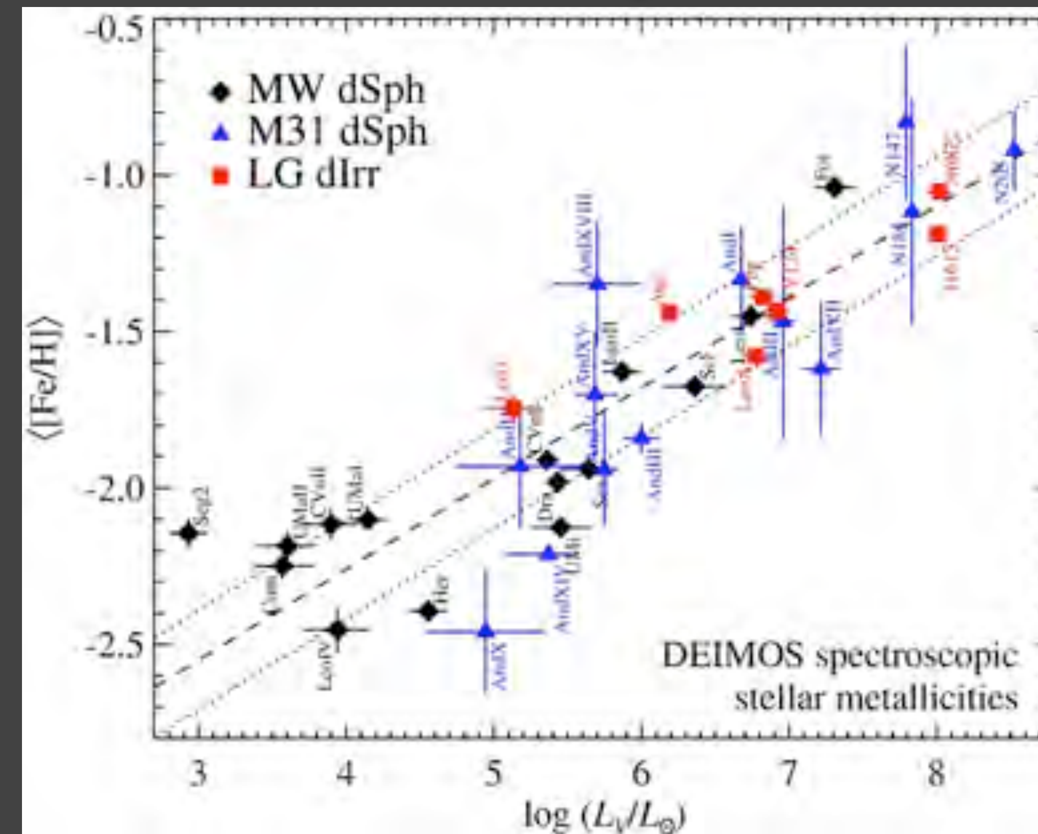


Lensing w/HST data gives smaller uncertainties.

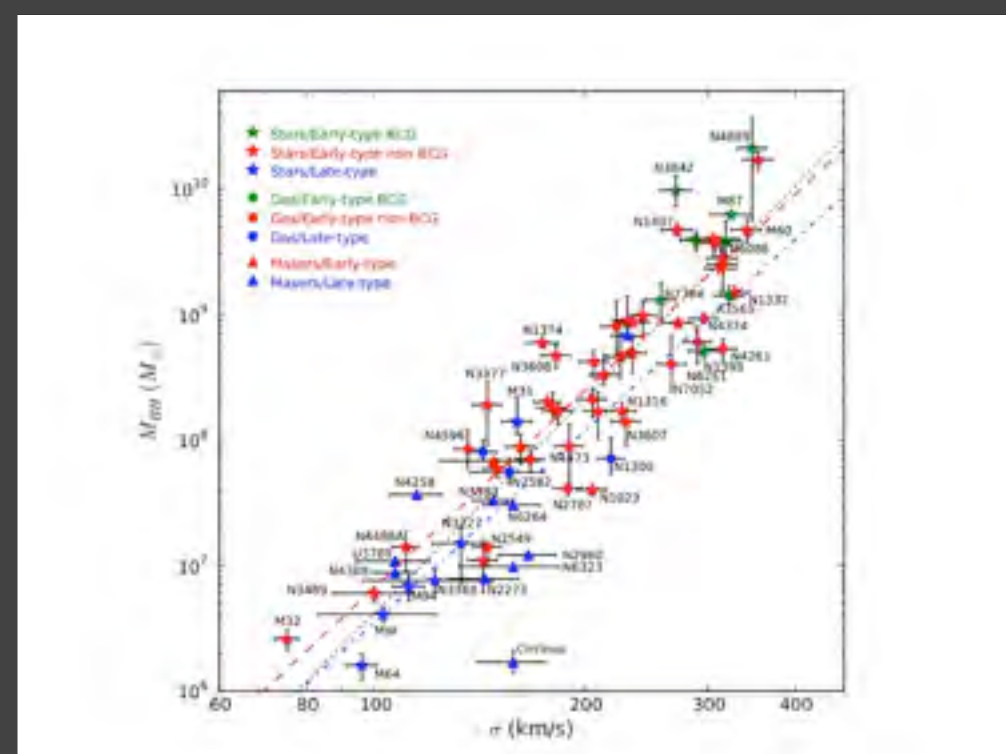
Scaling laws

- are Nature's way of trying to show us how it works.
- Gravitational potential or M/R (v^2) is a key property of matter halos
- Gravitational lensing M/R estimates are independent of assumptions of equilibrium, systematics different from other mass estimators

Star mass-star metallicity



Kirby+2013

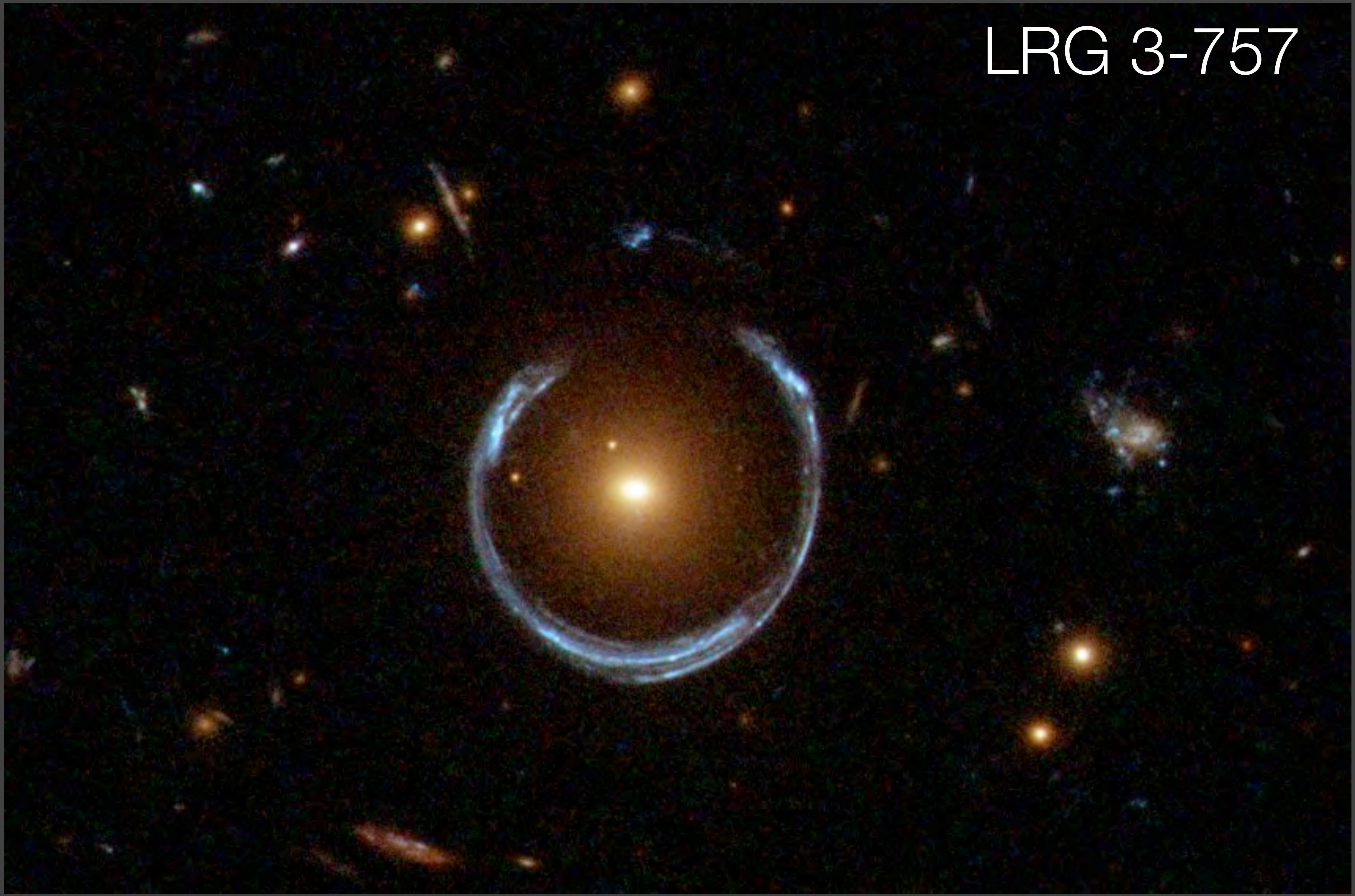


SMBH-galaxy velocity dispersion

McConnell & Ma 2013

Galaxy masses from lensing

Discovery and characterization possible with WFIRST



Strong Lensing
mass measurements of individual galaxies

figure from CLASH data
courtesy Marc Postman

but WFIRST choice of the
bluest filter might matter

The nature of collisionless (?) dark matter

Strong Lensing: testing the nature of dark matter

Abell 3827

Image credit ESO

Massey+2015

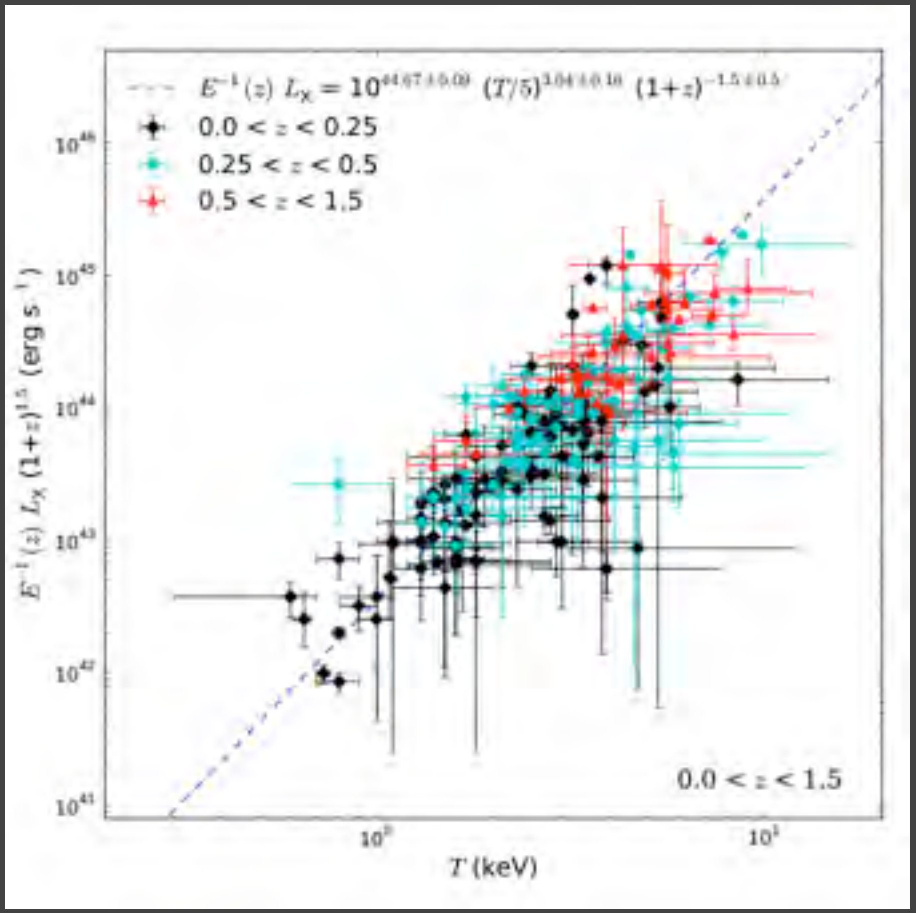
RCS2 032727-132623

Rigby+2012

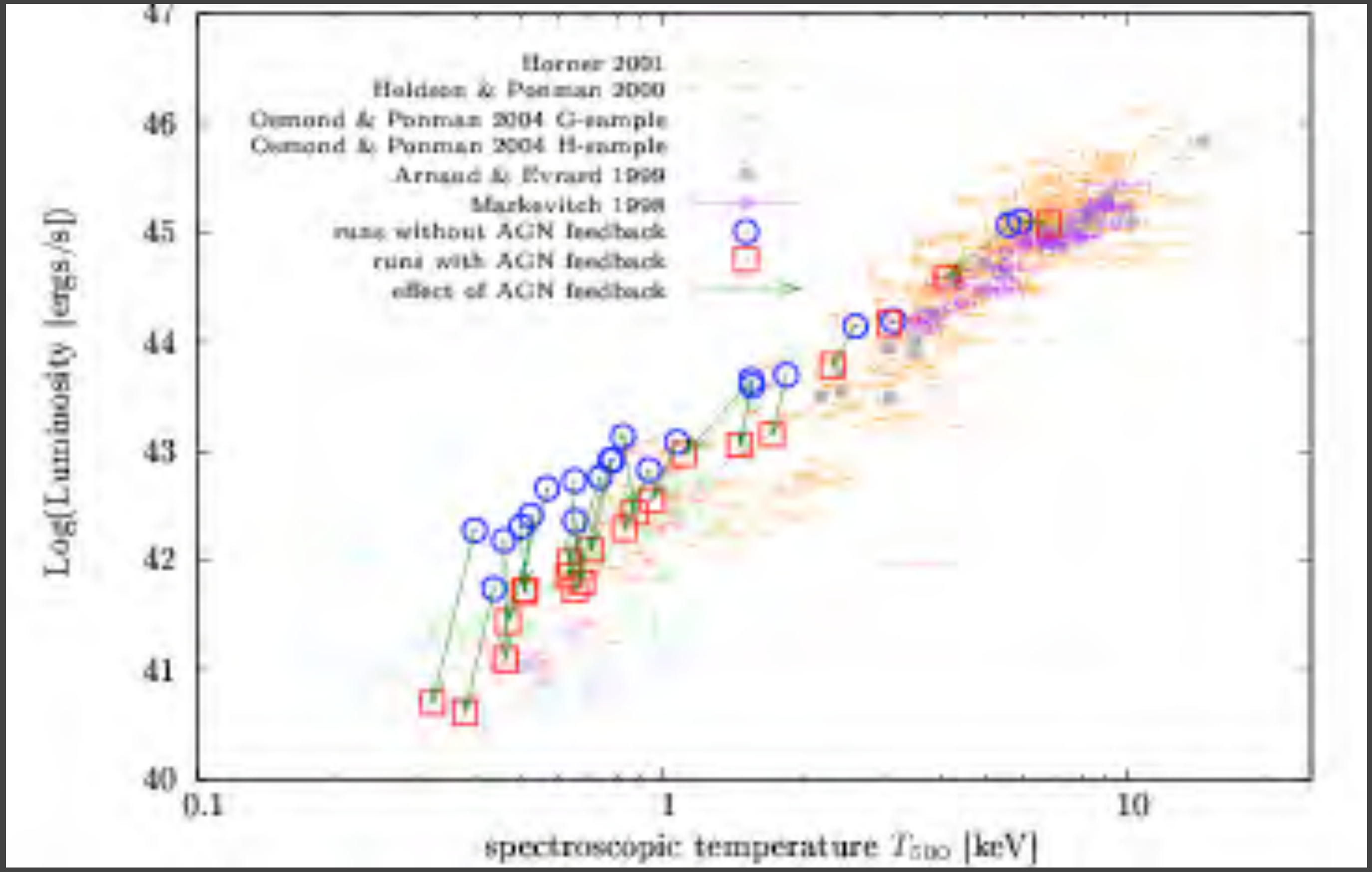
Understanding galaxy evolution

Feedback

- $L_X \sim T^3$ indicates IC gas entropy is elevated (cold infall gives $L_X \sim T^2$) (Kaiser+1986, 1990) [T ~ M/R]
- Feedback is required to explain this scaling relation.



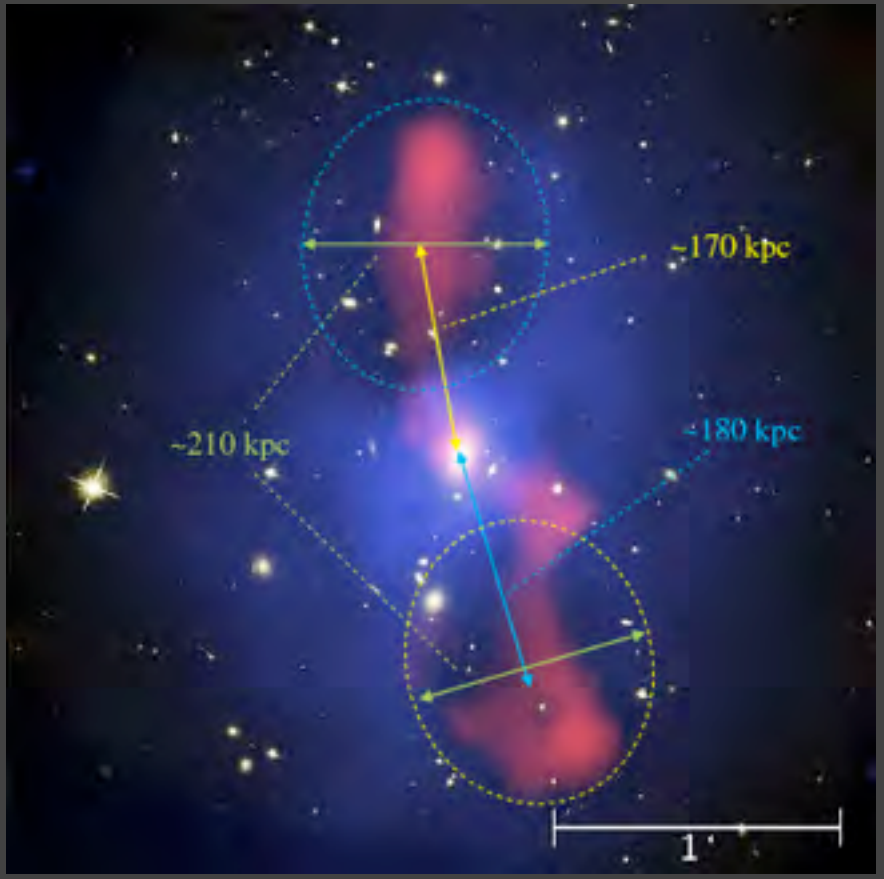
XMM cluster survey, (Hilton+2012)



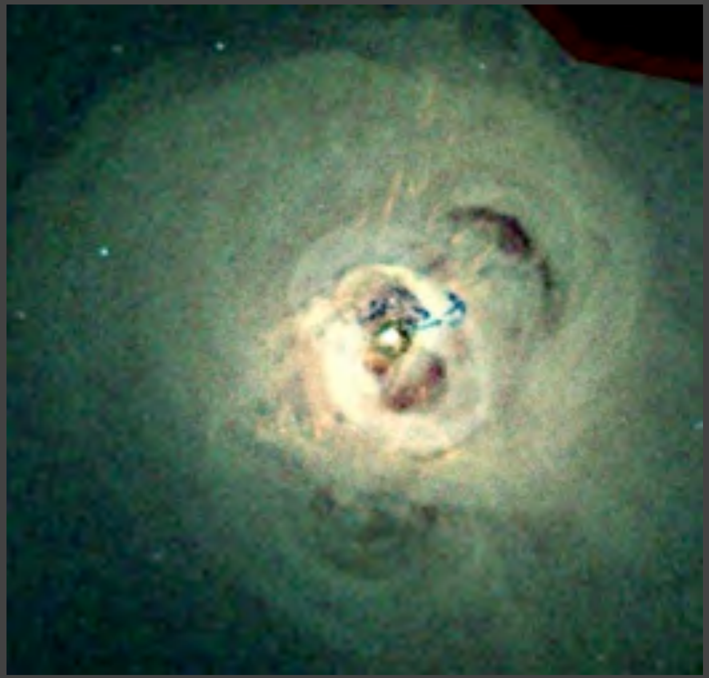
Blue: no BH feedback
Red: with BH feedback
(Puchwald+2008)

Feedback

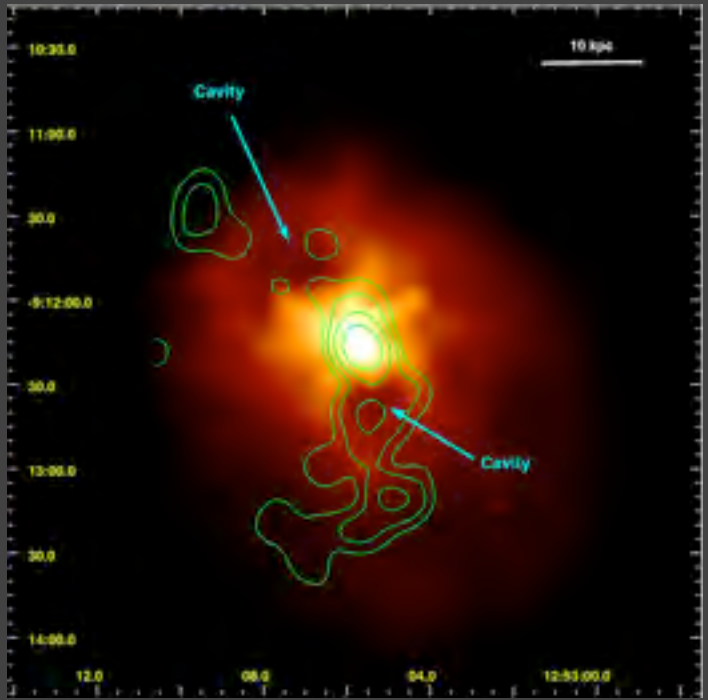
- $L_X \sim T^3$ indicates IC gas entropy is elevated (cold infall predicts $L_X \sim T^2$) (Kaiser+1986, 1990) [$T \sim M/R$]
- Cluster atmospheres show evidence of powerful AGN outbursts and AGN-driven metal enrichment.



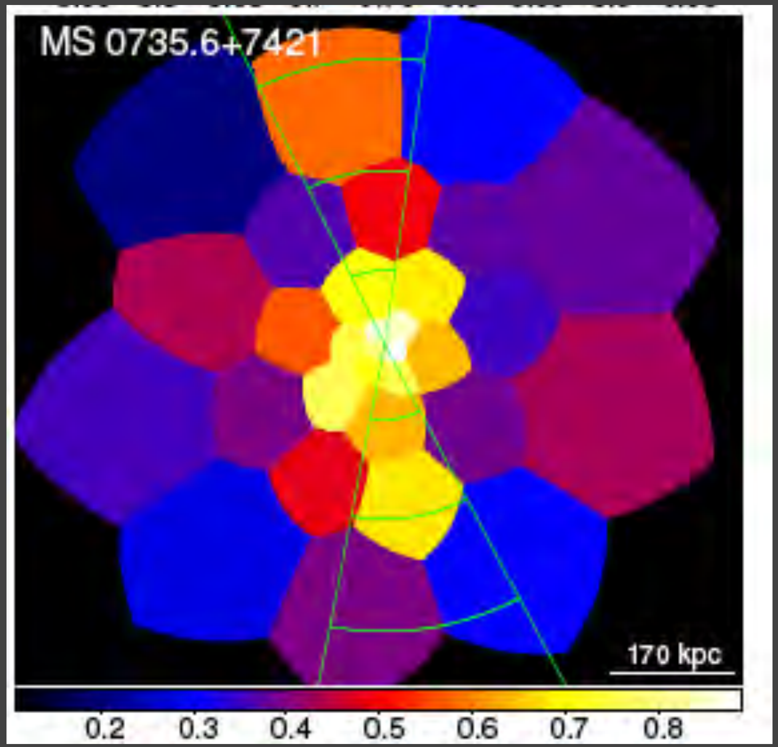
McNamara+2009; figure f/ Sternbach+2009



Perseus; Fabian+2005



HCG62; UBirmingham

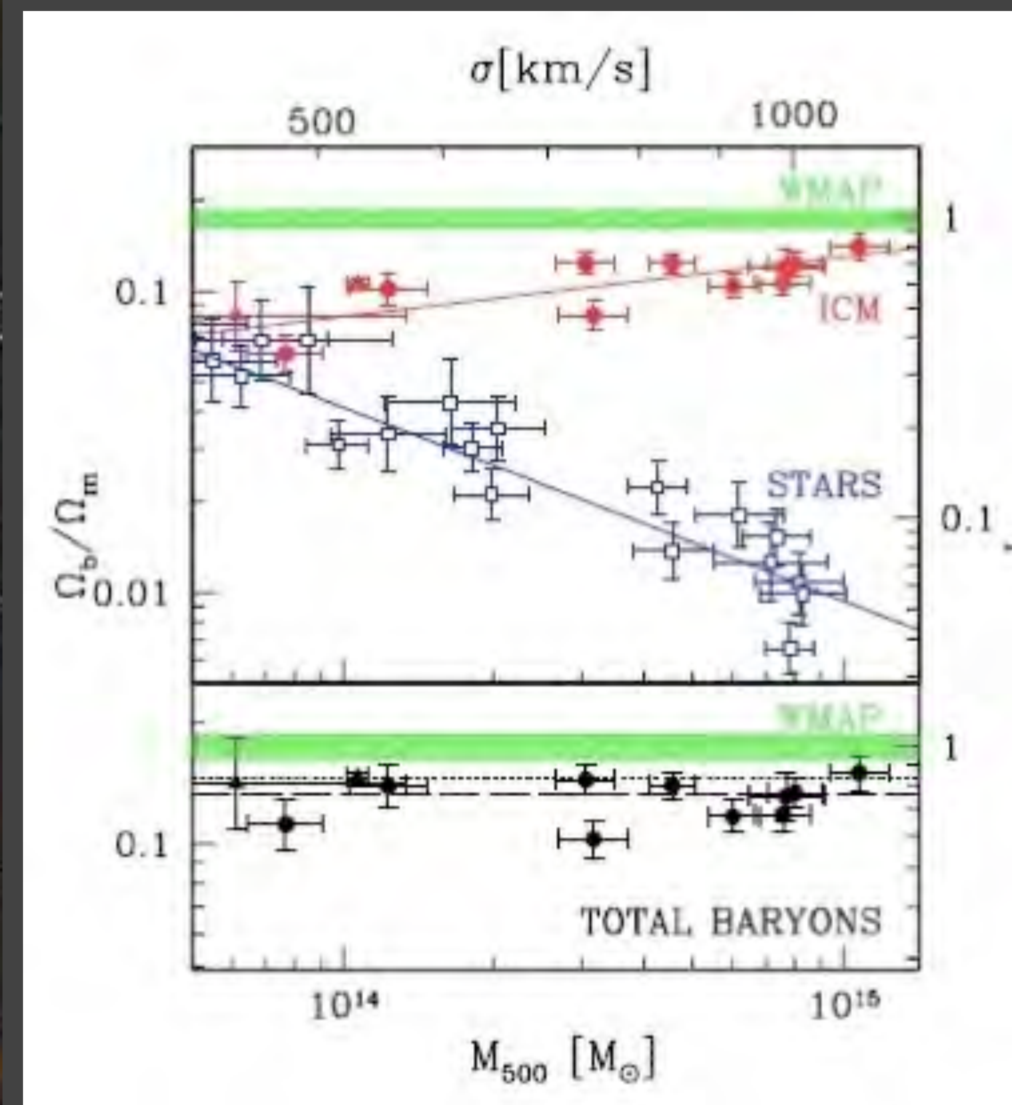


MS0735; Kirkpatrick & McNamara 2015

AGN and stellar feedback depend on system gravitational potential.

Baryon census: Intracluster/ intergalactic stars

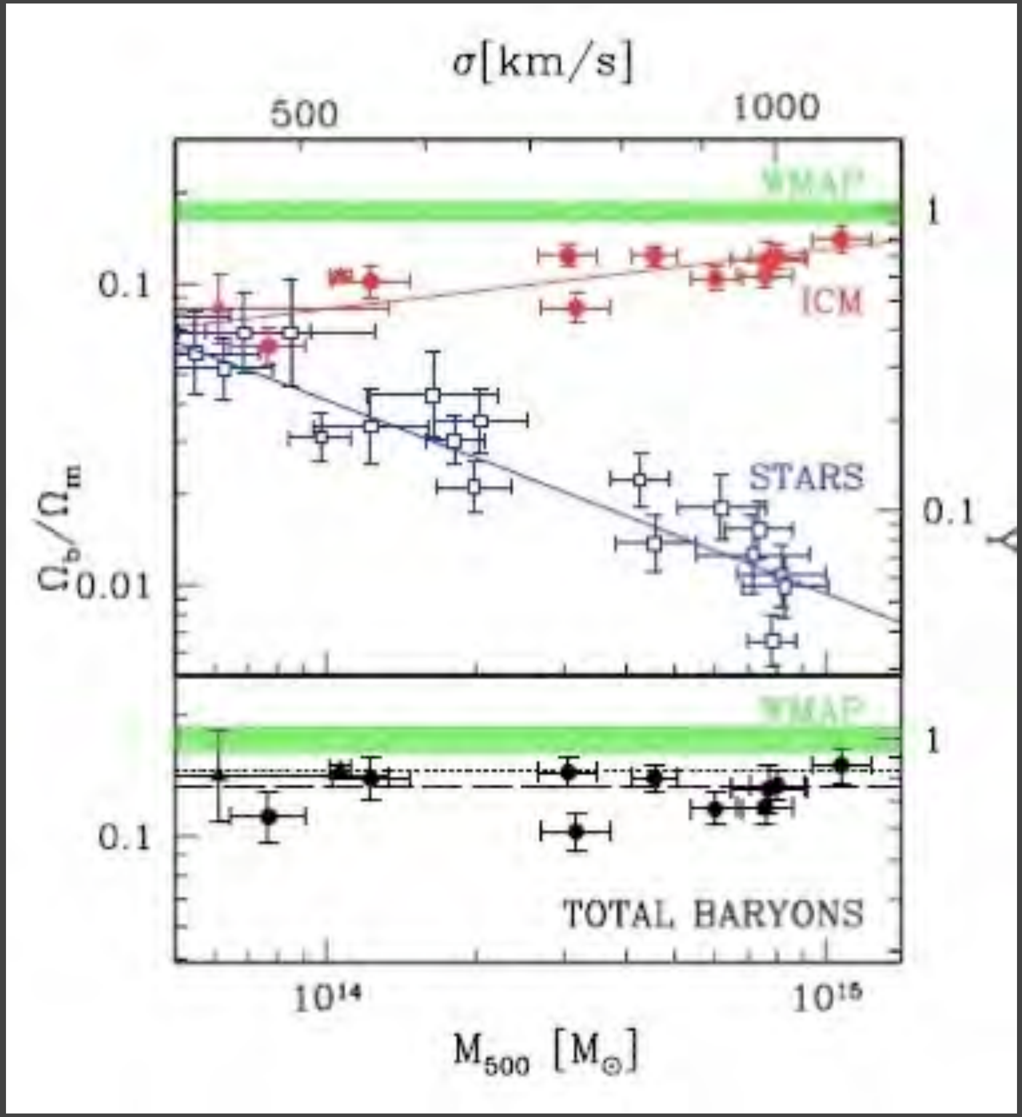
Gonzalez+2007



Baryon census: Intracluster/ intergalactic stars

Gonzalez+2007

- Fraction?
- Evolution with redshift?
- Metallicity high or low?
- Difficult to measure: WFIRST low background, high resolution will make it easier.
- Difficult to model

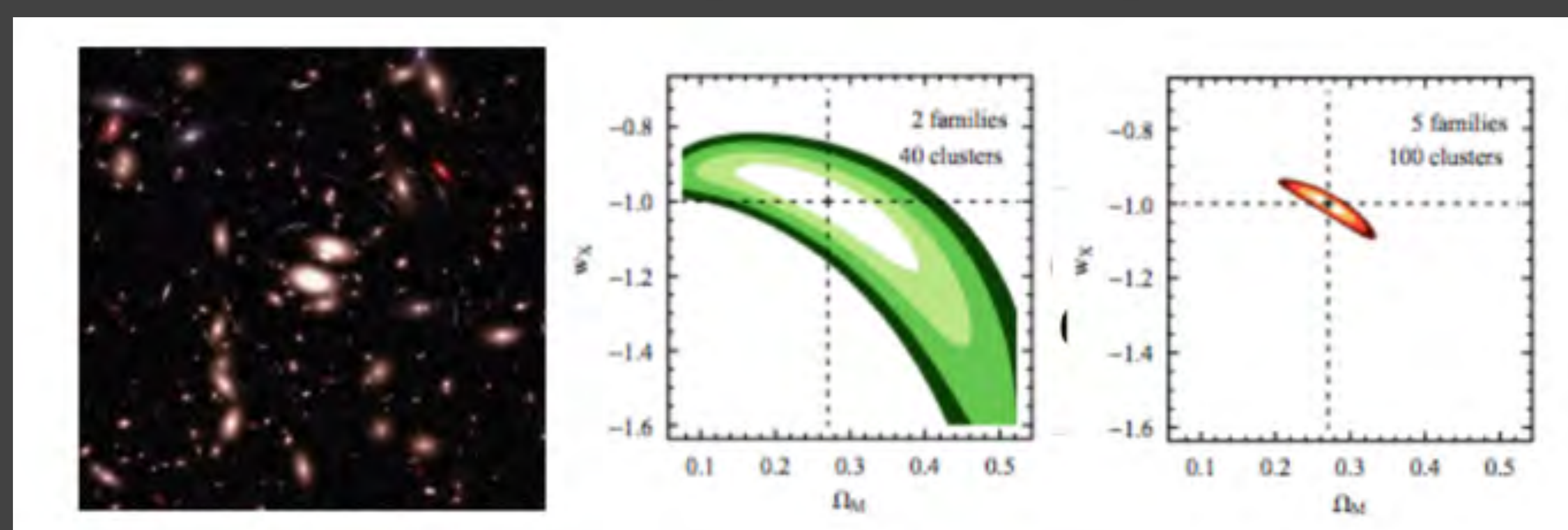


Cluster Cosmology

- Cluster number N(z,M) and spatial clustering are exquisitely sensitive to cosmological parameters such as Ω_m, σ_8.
- Cluster N(z,M) tests alternative-GR explanations for dark energy, and can be cross-calibrated.
- Selection by significance of lensing peak “clean”, and can be simulated.

Image credit: Meneghetti & Natarjan

HST synthetic image w/ SL.
Recovery of cosmological constants, simulated.



Science considerations for cluster science with WFIRST

- Choice of fields for the high-latitude survey: optimal overlap with other surveys: LSST, Euclid, eRosita, SZ, spectroscopy.
- Observation strategies: dithers, depth
- Optimal number and type of pointed observations towards the most massive (and therefore rare) systems.
- Filter choices: blue range for increased strong lensing contrast; redder coverage for better sampling of the stellar peak.
- Much work needed: simulators, lensing experts, and survey experience required.

WFIRST cluster science

- systematics-limited lensing masses for clusters and groups and a subset of galaxies
- discovery and characterization of distant and massive clusters with a well-defined selection method
- dark matter characterization: radial distributions, tests of collisionless nature
- mass scaling laws (including trends and scatter) to test and inform our understanding of how galaxies and AGN evolve
- Cluster galaxy evolution, galaxy stellar light, intracluster stars

WFIRST will transform the nature of cluster science

- Vastly increased samples of accurate mass measurements of individual systems: can quantify mean and mass trends and scatter and evolution.
- Quantifiable selection bias independent of system state (such as equilibrium, virialization)
- High quality, large-area measurements of mass fields
- Low sky, low instrumental noise measurements of faint stellar light over large areas