Galaxy clusters: the Universe’s biggest labs

Matteo Bianconi

Image credit: Illustris-TNG simulation

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An *extragalactic* guide to the talk

We will:

- travel outside our Galaxy
- combine observations and numerical simulations
- jump back-and-forth in Time and see Space stretching
What is "environment"?

Image credit: SDSS + NASA

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Satellite view of CERN

Image credit: Google Earth + NASA

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Hot sparse gas emitting X-rays

- 10 million Kelvin!
- 1 particle per cubic centimeter!

5 times more gas than galaxies

Image credit: NASA (Chandra)
Cluster Mergers are the most energetic events in the Universe since the Big Bang

ZuHone+ 2012
Numerical simulation of hot gas dynamics

Observations

ZuHone+ 2012

Perseus Cluster, Chandra 2017

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WAT IS "ENVIRONMENT"?
Galaxy clusters can be used as space telescopes

“...Matter tells space how to curve” [J. Wheeler]
Materia oscura
Dunkle Materie
DARK MATTER
Σκοτεινή ύλη
Matière noire

Fritz Zwicky - 1933

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Galaxies

- Hot gas: 11%
- Dark matter: 87%

Galaxy cluster mass budget
Predicting Supernova appearance

Kelly+ 2015

October 30, 2015

December 11, 2015
Gravitational lensing of gravitational waves

SMACS0304 GMOS imaging and difference image

A3084 GMOS imaging and difference image
Why clusters are important labs

• Large scale evolution:
  Benchmark for cosmological models
  Test for nucleosynthesis

• Environmental effects on galaxy evolution:
  How clusters shape galaxy activity
  Test new probes for galaxy quenching

• Gravitational lensing:
  Towards multi-messenger astronomy
  New probes for General Relativity
Birmingham involvement

• **Large scale evolution:**
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Birmingham involvement

Galaxy evolution with LSST

X-ray with eROSITA

Lensing with Euclid

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Birmingham involvement

Galaxy evolution with LSST

Lensing with Euclid

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"Along with ‘Antimatter,’ and ‘Dark Matter,’ we’ve recently discovered the existence of ‘Doesn’t Matter,’ which appears to have no effect on the universe whatsoever."
Thank you

Image credit: Illustris-TNG simulation

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