# Galaxy clusters: the Universe's biggest labs

Matteo Bianconi

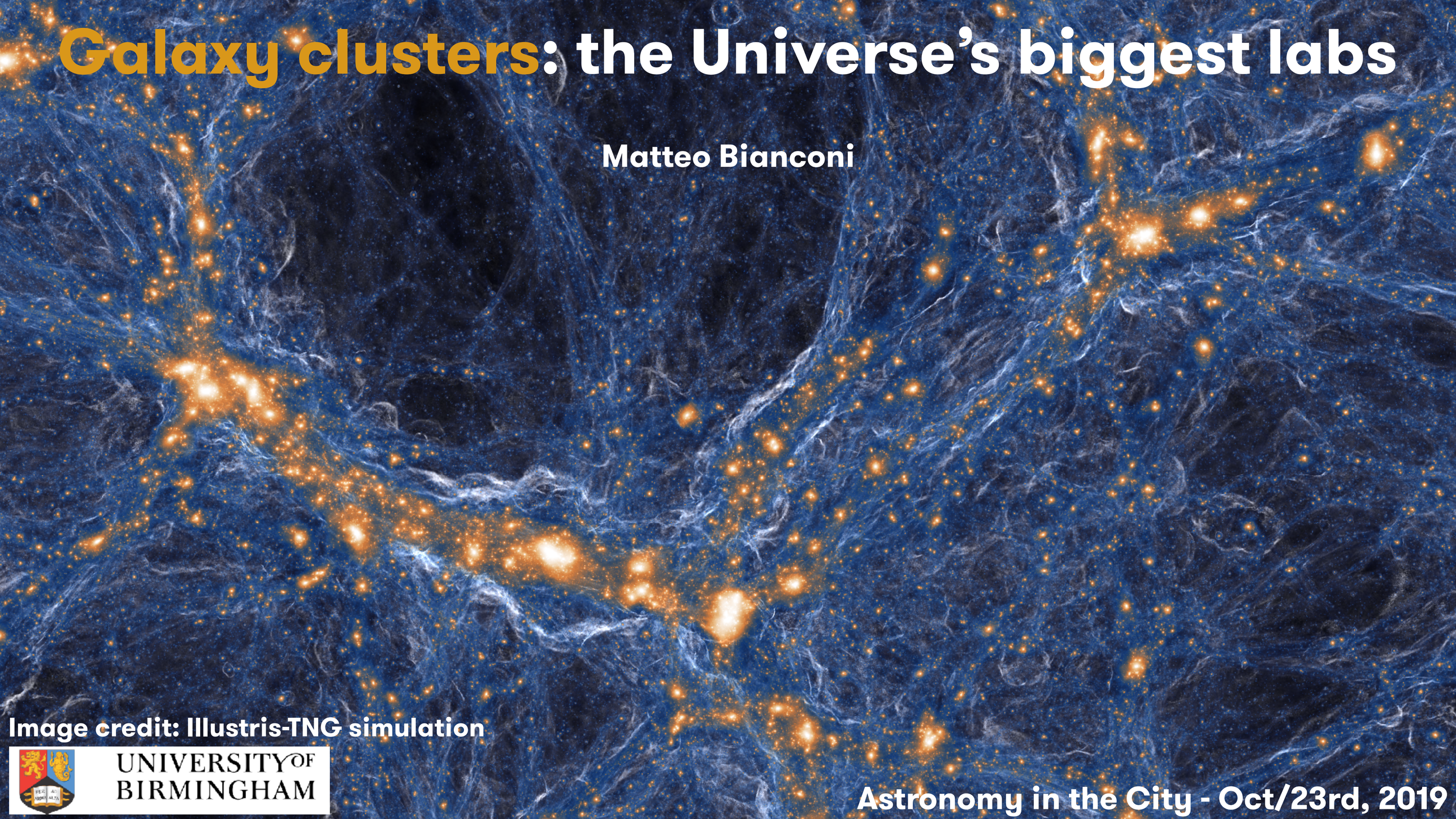


Image credit: Illustris-TNG simulation

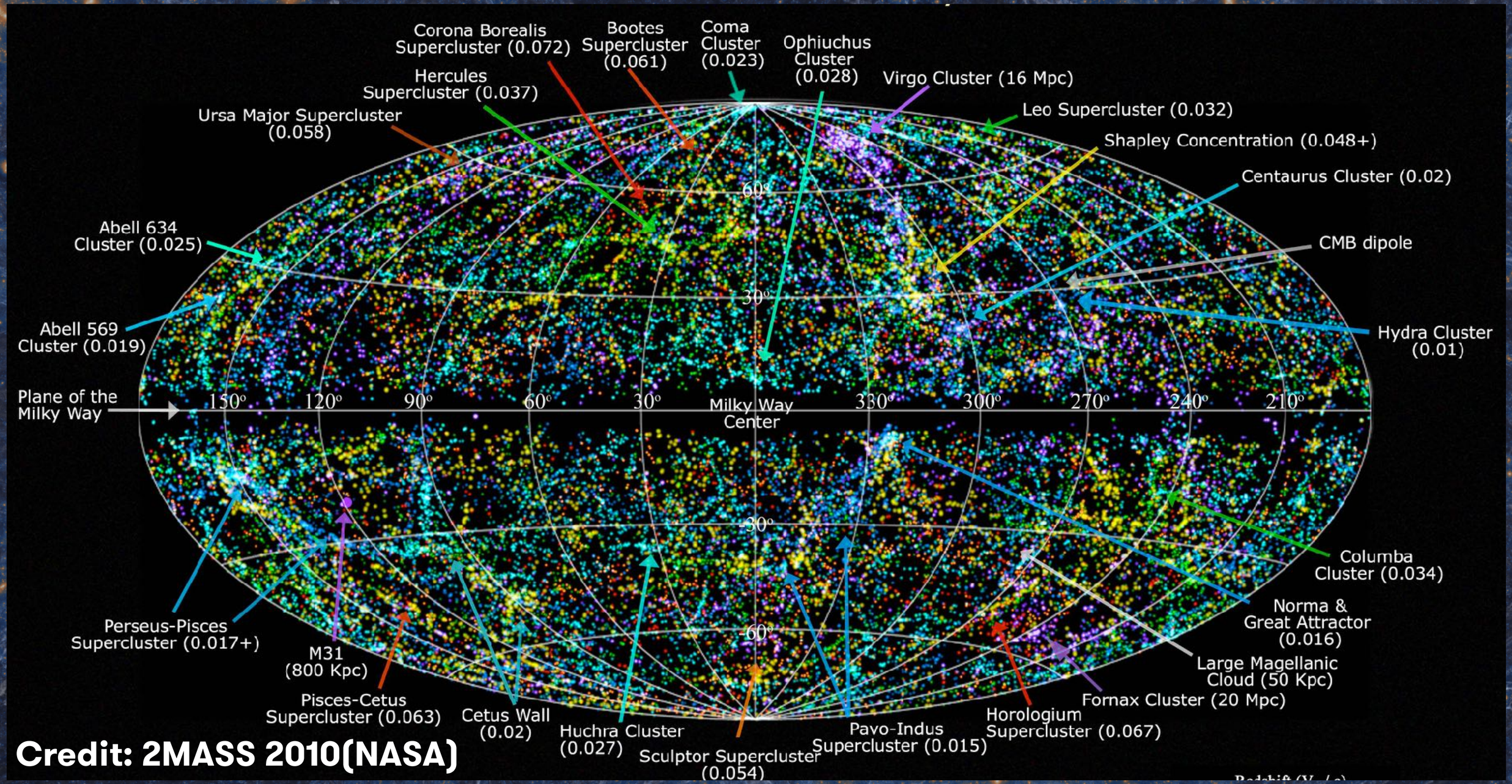
UNIVERSITY OF BIRMINGHAM

Astronomy in the City - Oct/23rd, 2019

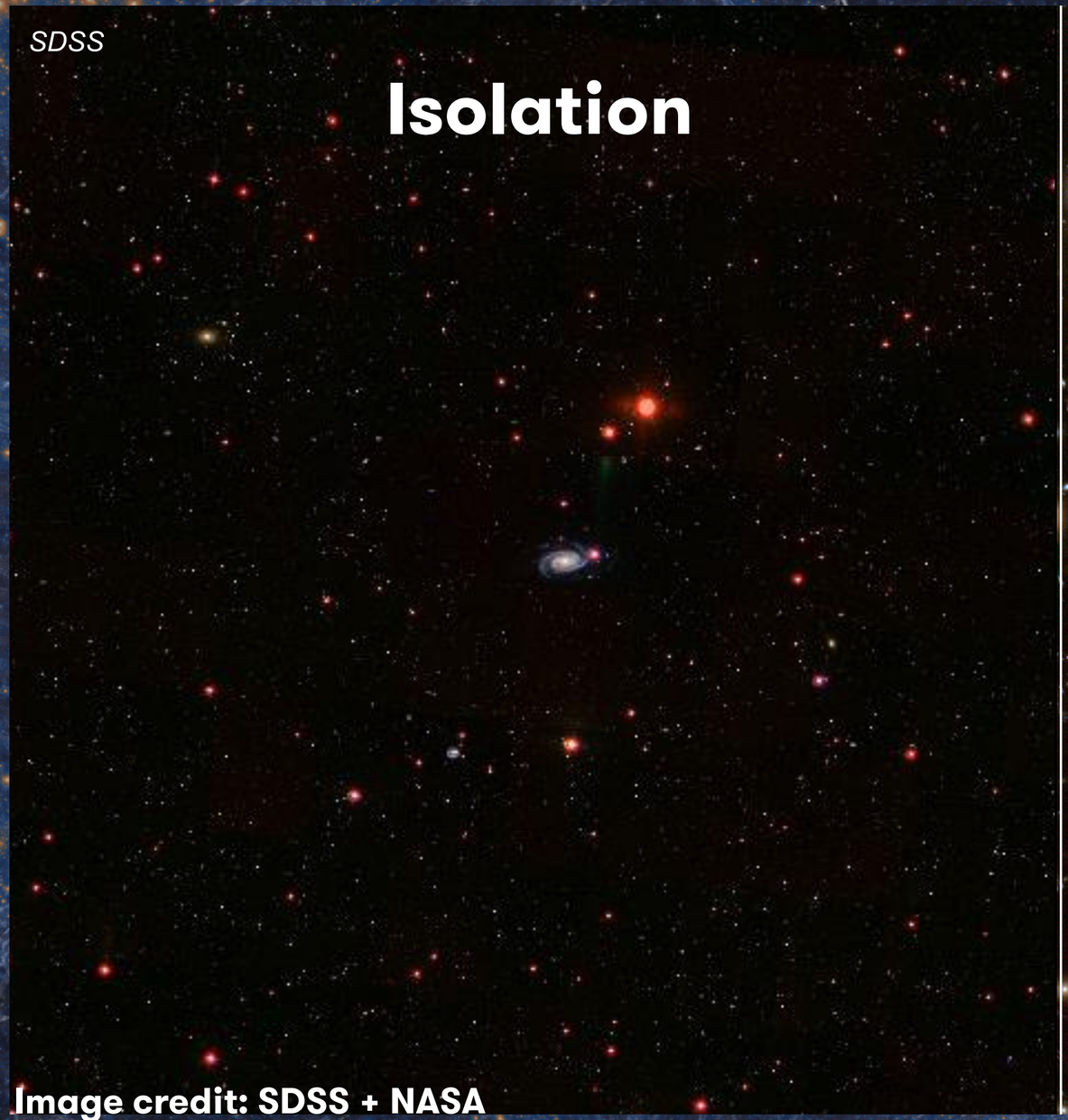
# An extragalactic guide to the talk

We will:

- travel outside our Galaxy
- combine observations and numerical simulations
- jump back-and-forth in Time and see Space stretching




**Credit: 2MASS 2010(NASA)**



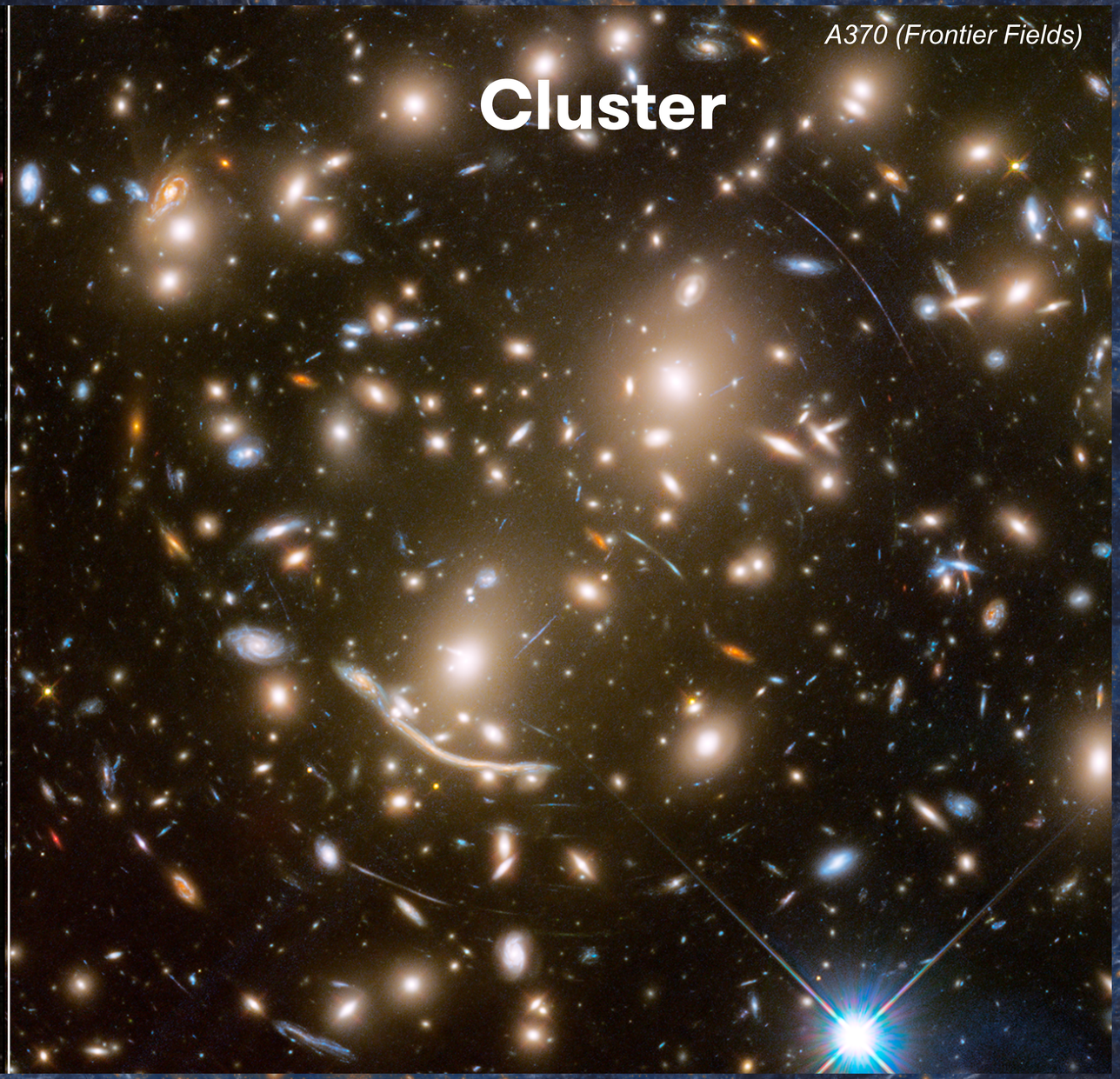
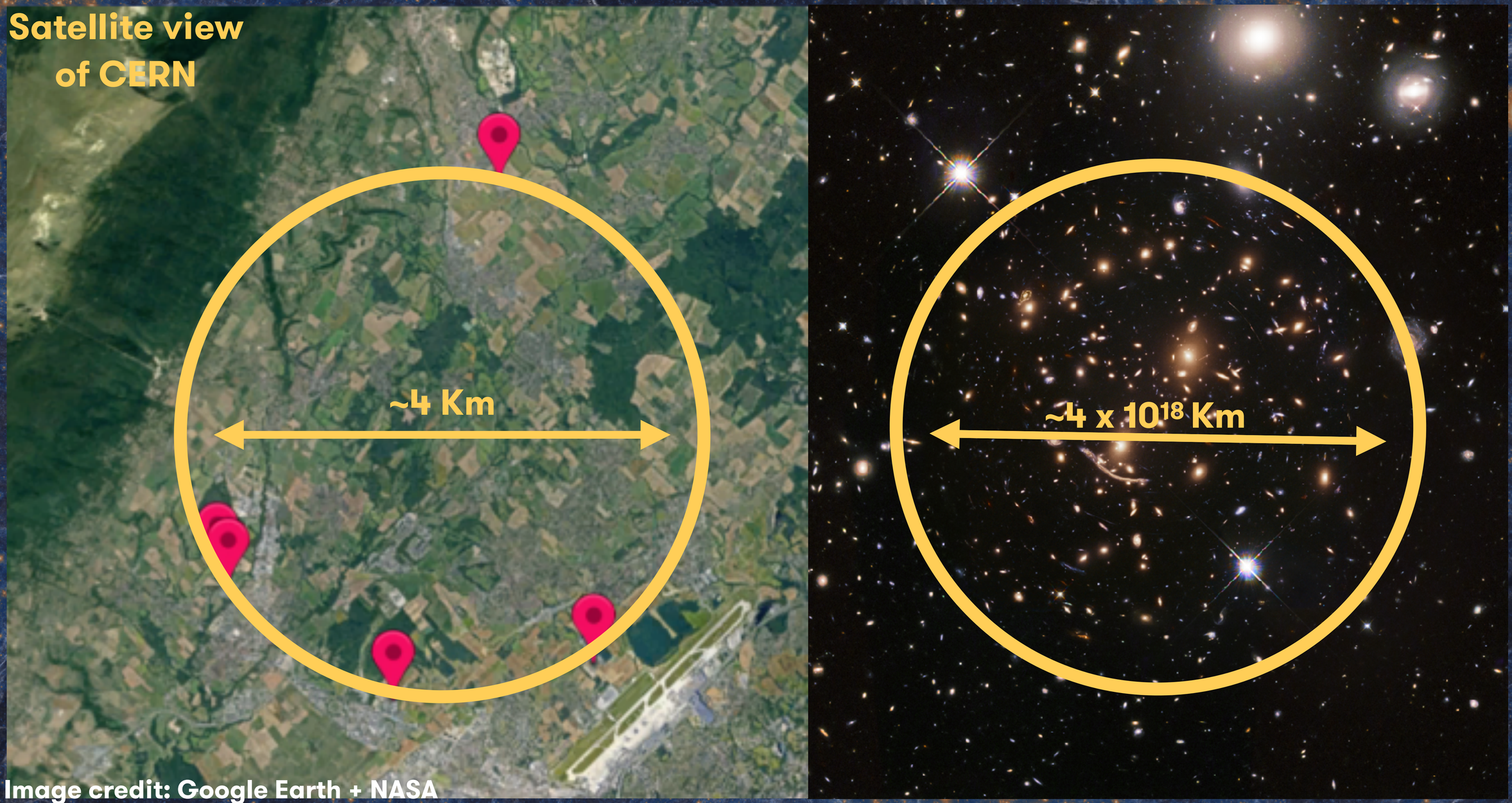



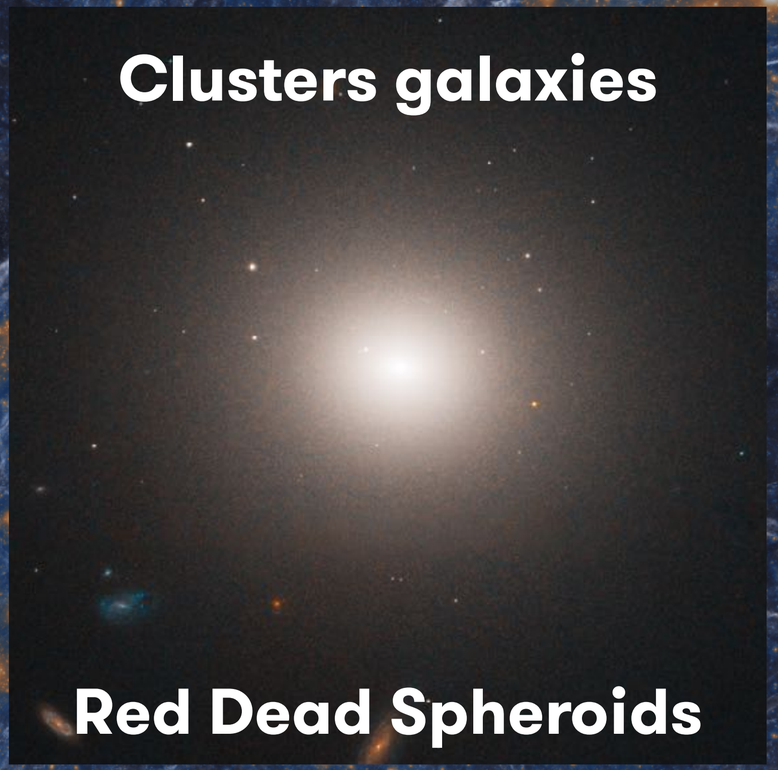

Image credit: SDSS + NASA


Satellite view
of CERN
~4 Km
~4 x 10^18 Km
Image credit: Google Earth + NASA

Isolated galaxies

Blue Active Spirals

Clusters galaxies



Red Dead Spheroids

Image credit: ESO

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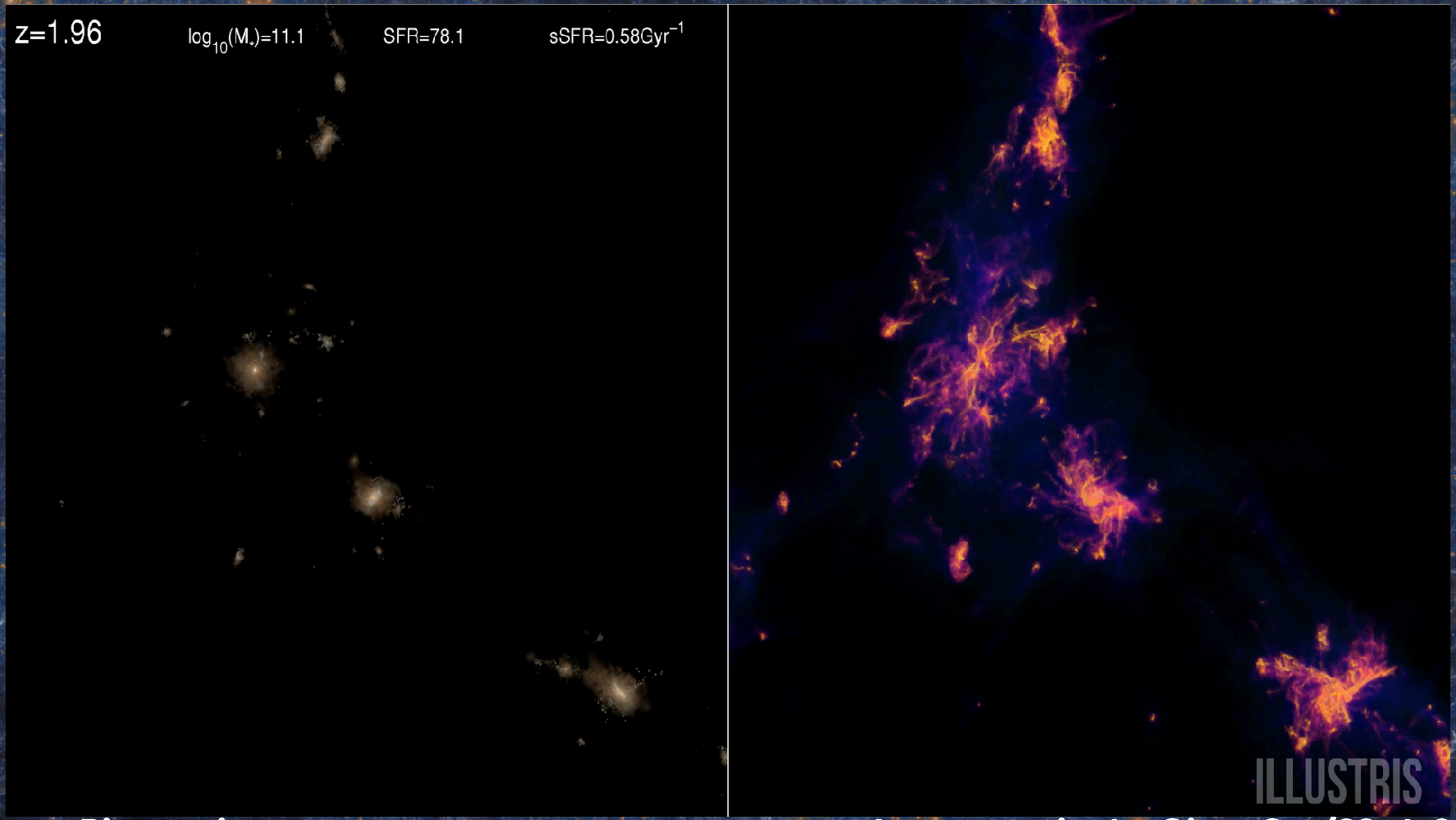
z=1.96
log10(M*)=11.1
SFR=78.1
sSFR=0.58Gyr−1
ILLUSTRIS

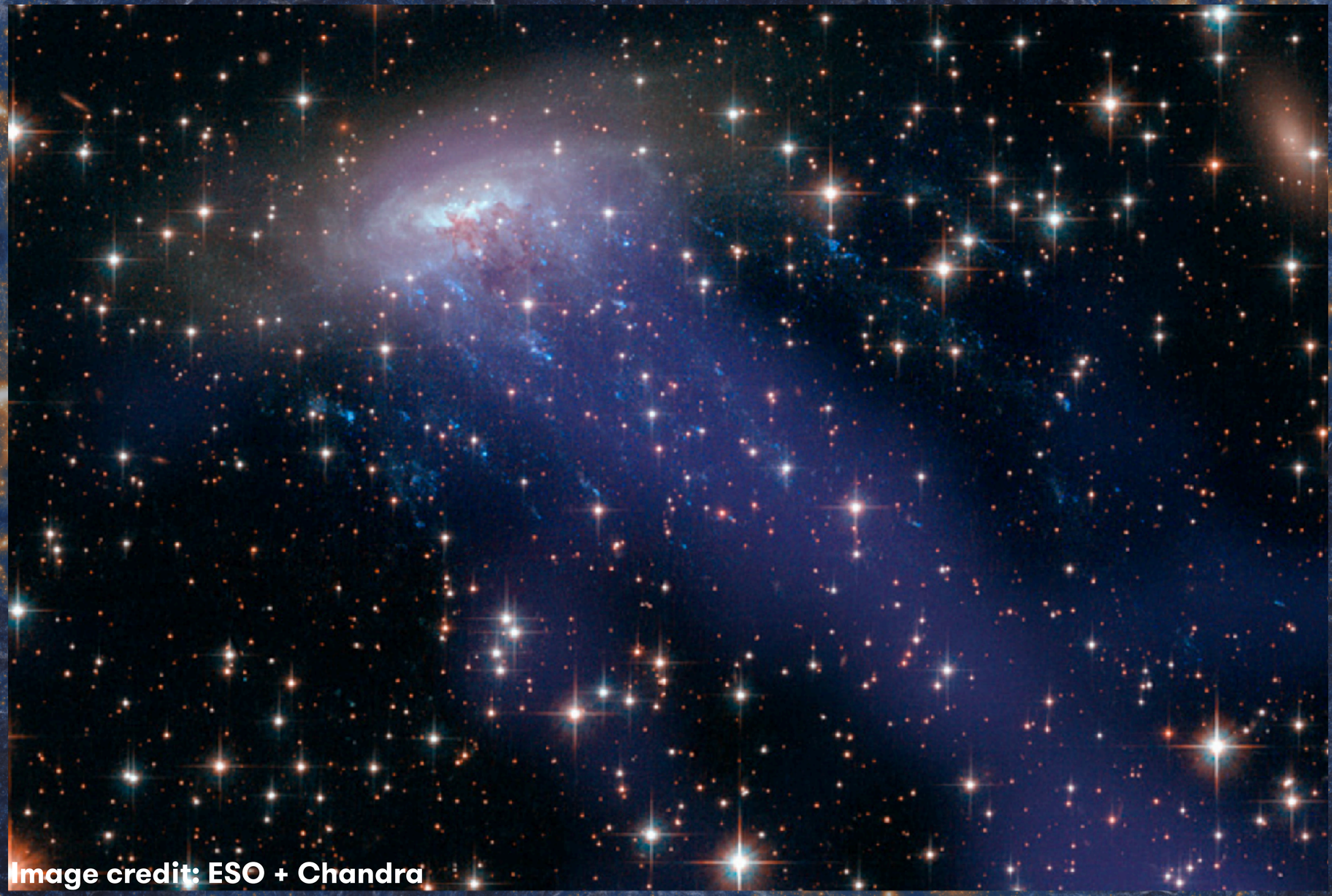
Image credit: ESO + Chandra

Image credit: NASA

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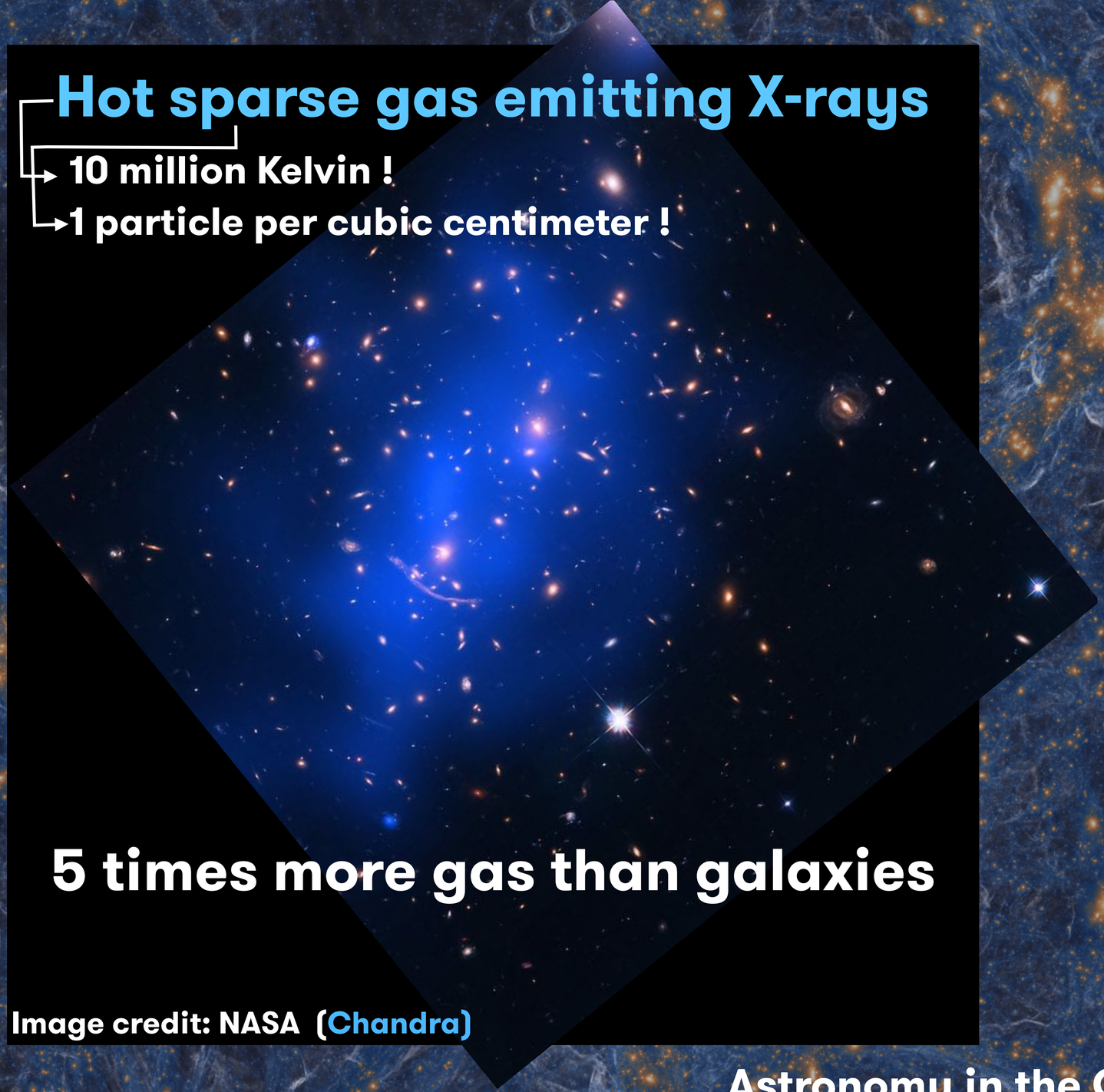
## Hot sparse gas emitting X-rays

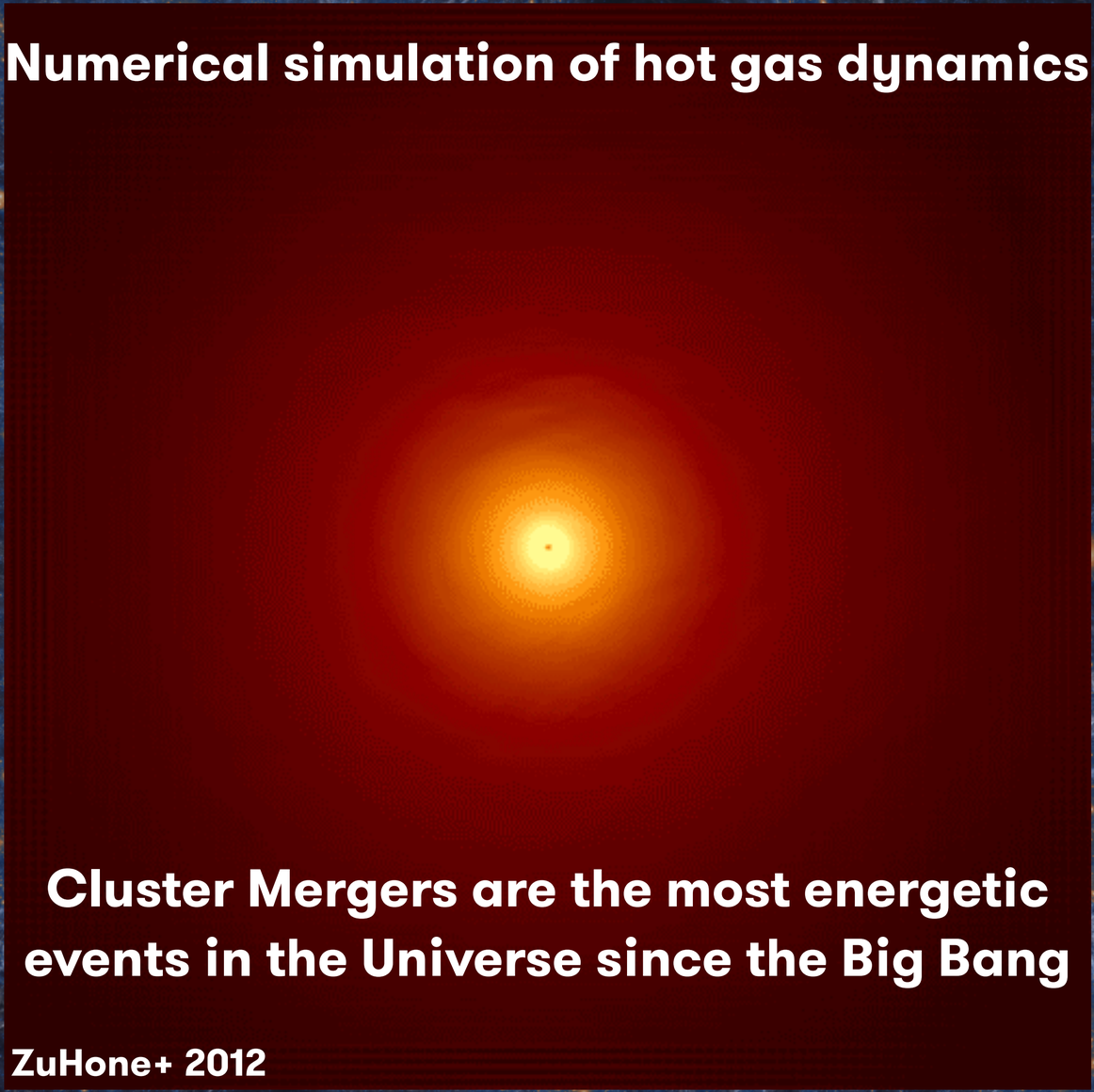
- 10 million Kelvin !
- 1 particle per cubic centimeter !



**5 times more gas than galaxies**

Image credit: NASA (Chandra)

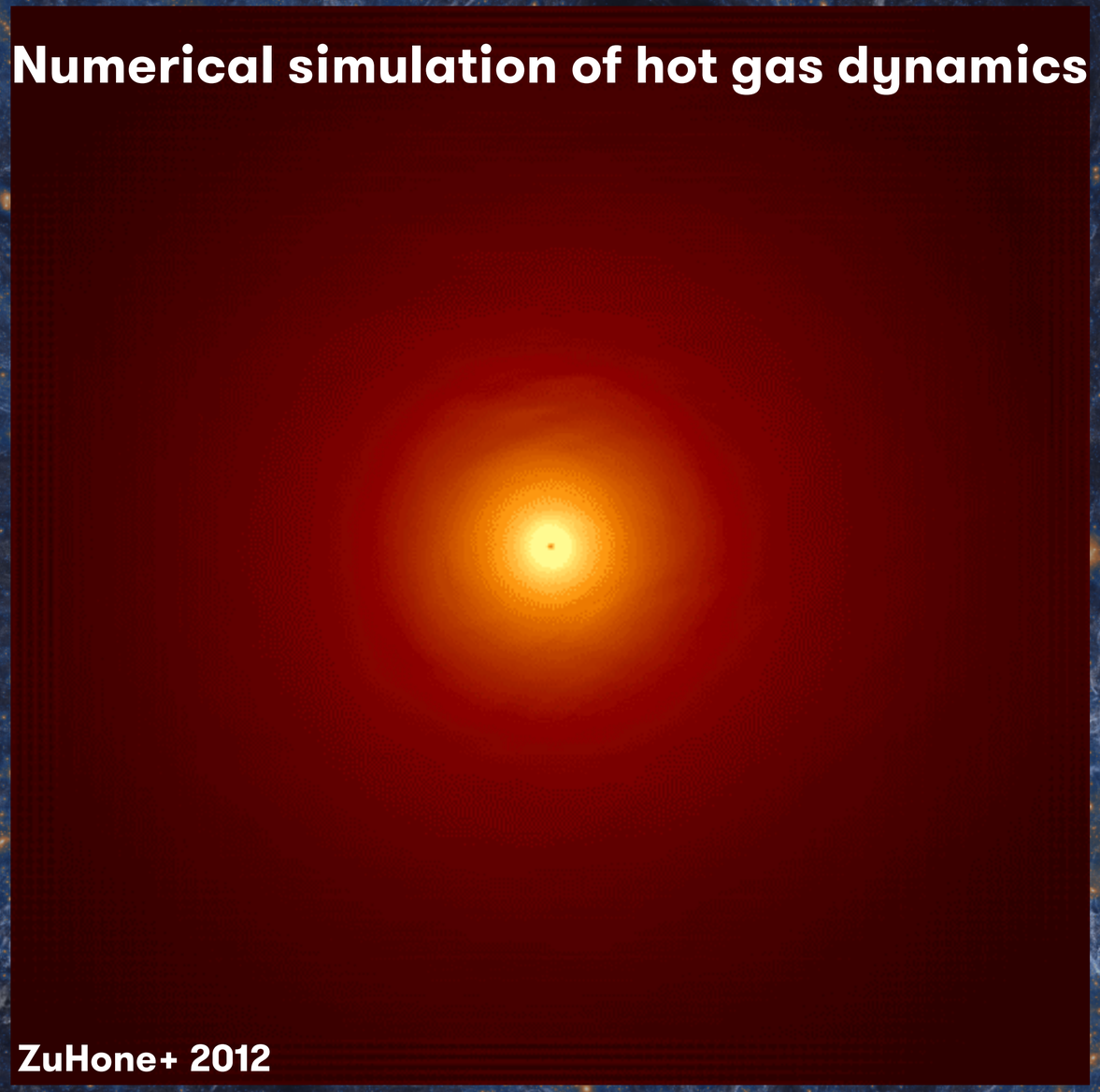
Numerical simulation of hot gas dynamics



Cluster Mergers are the most energetic events in the Universe since the Big Bang

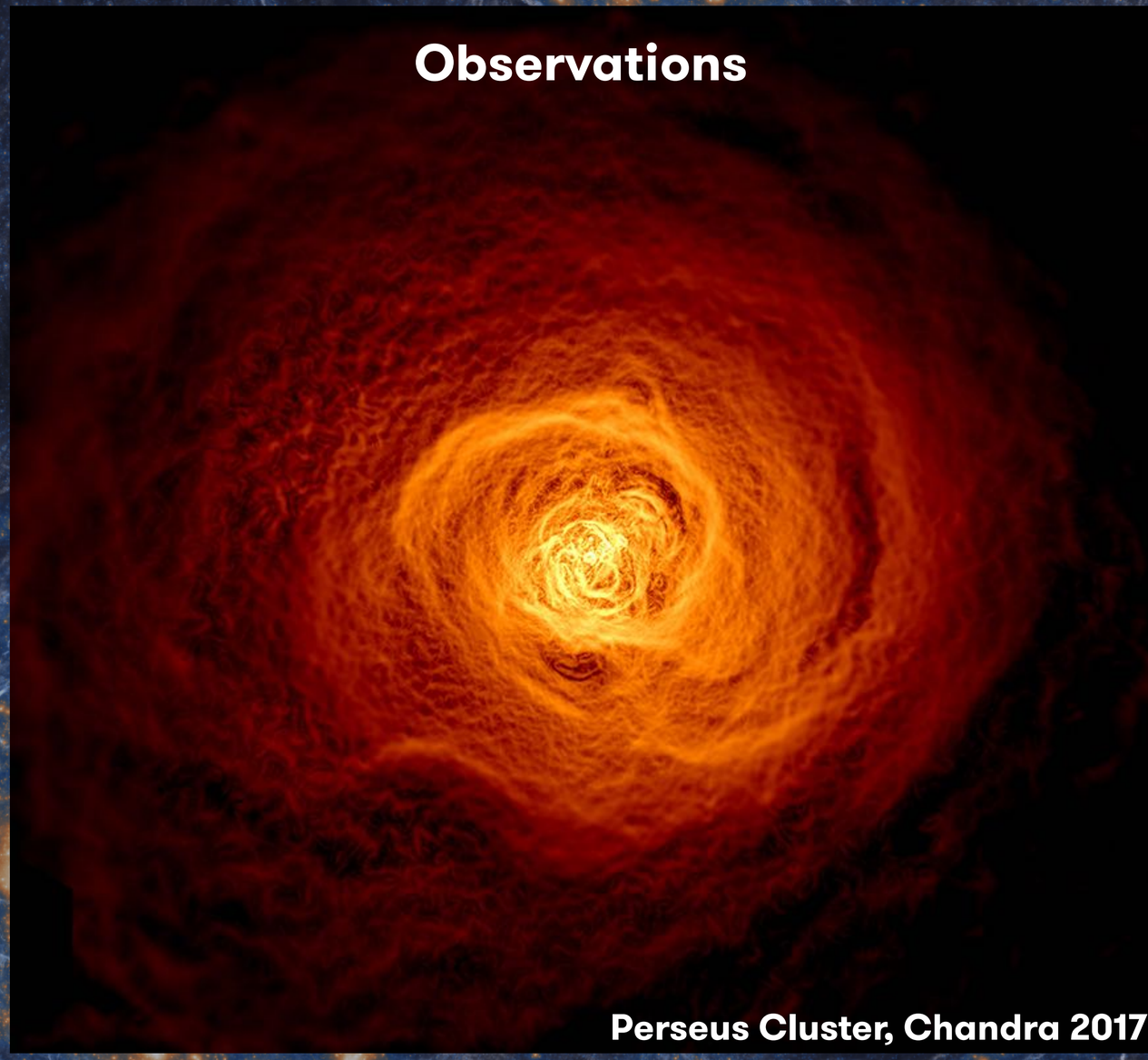
ZuHone+ 2012

## Numerical simulation of hot gas dynamics



ZuHone+ 2012

## Observations



Perseus Cluster, Chandra 2017

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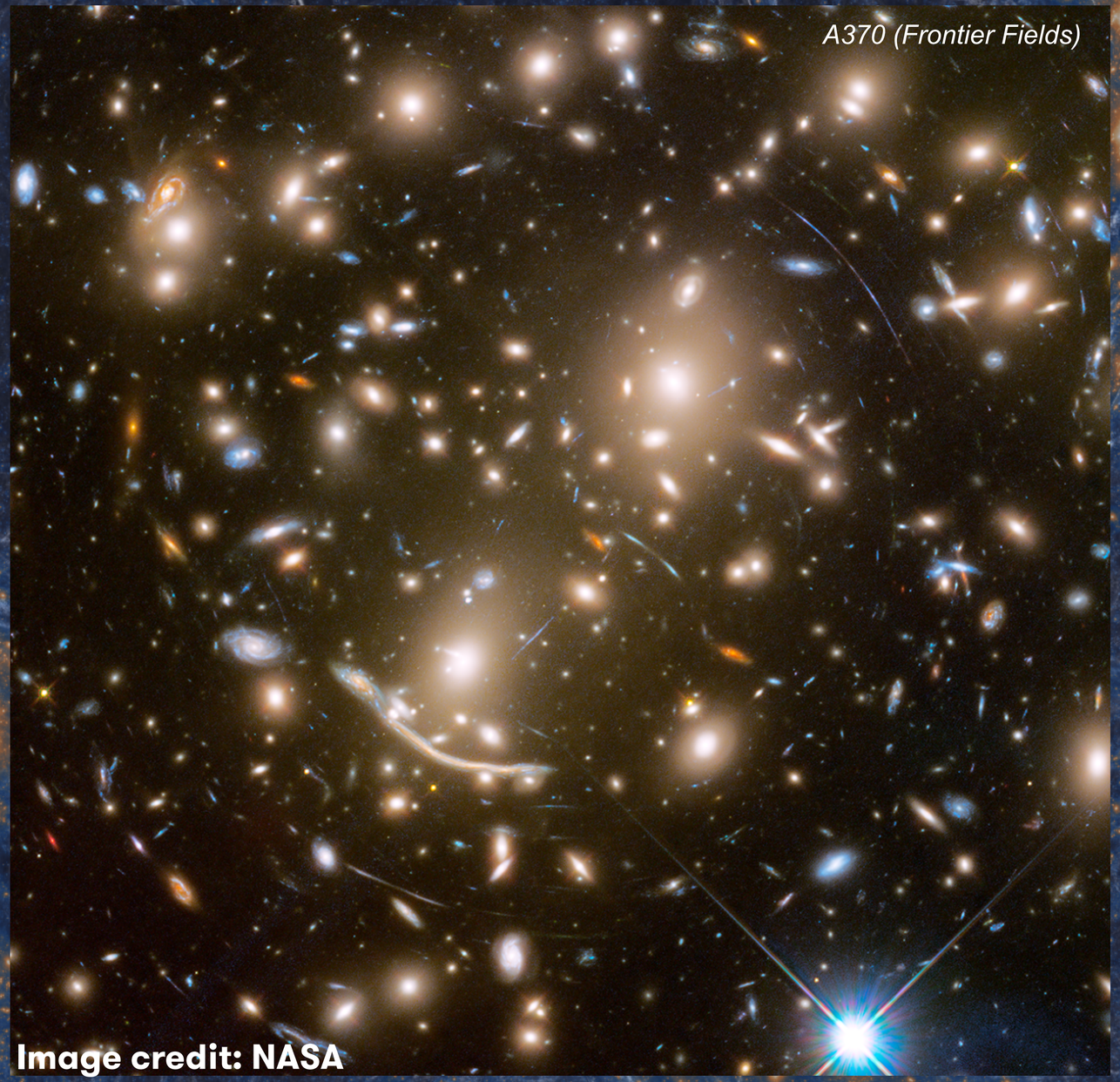
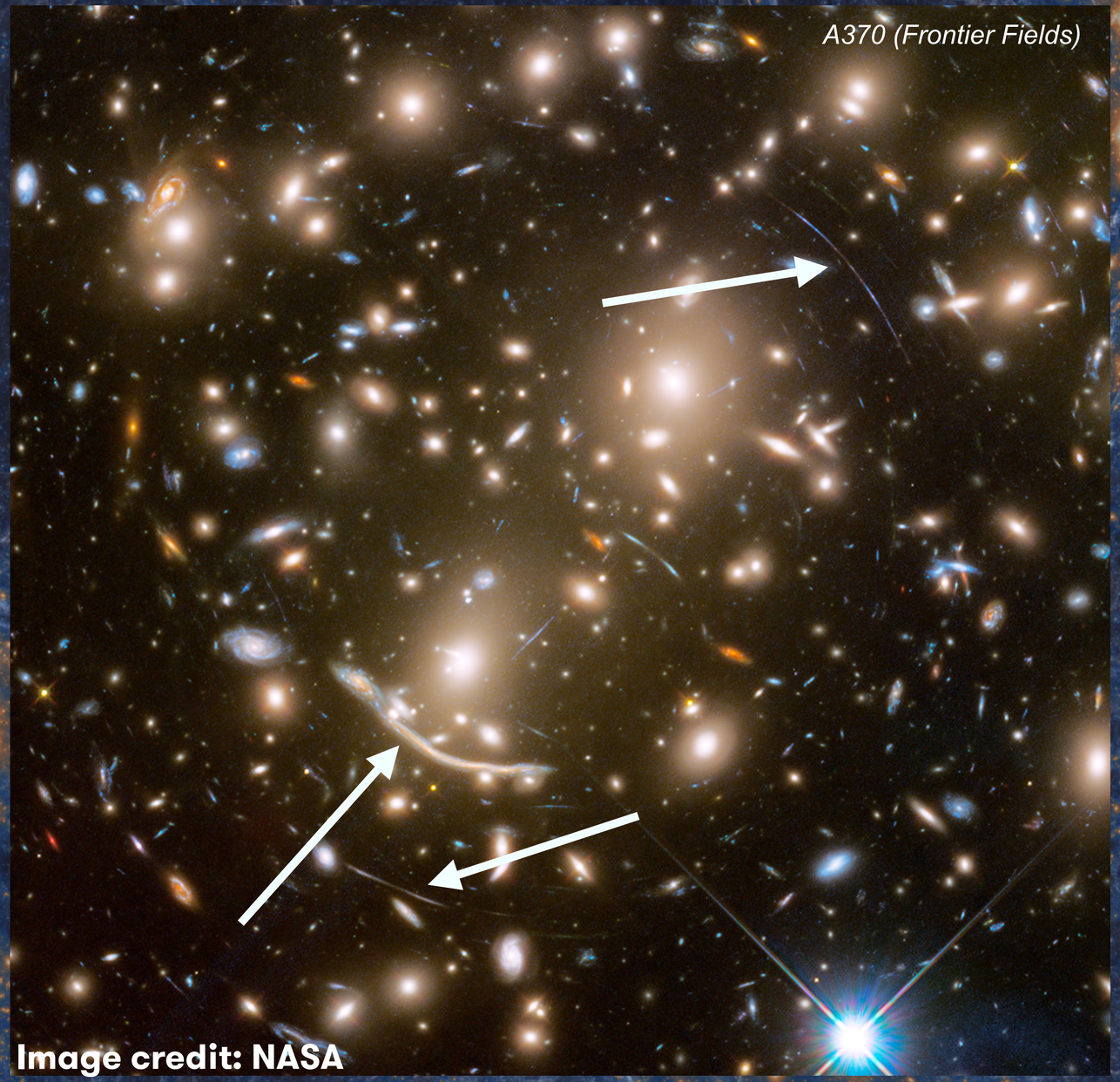
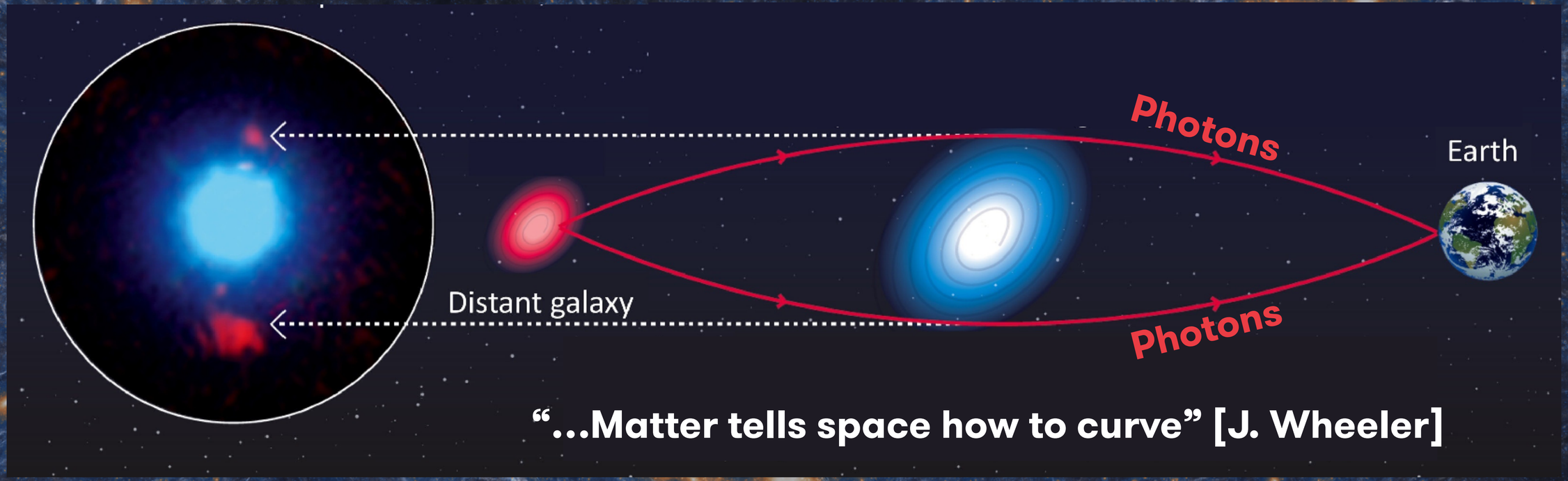
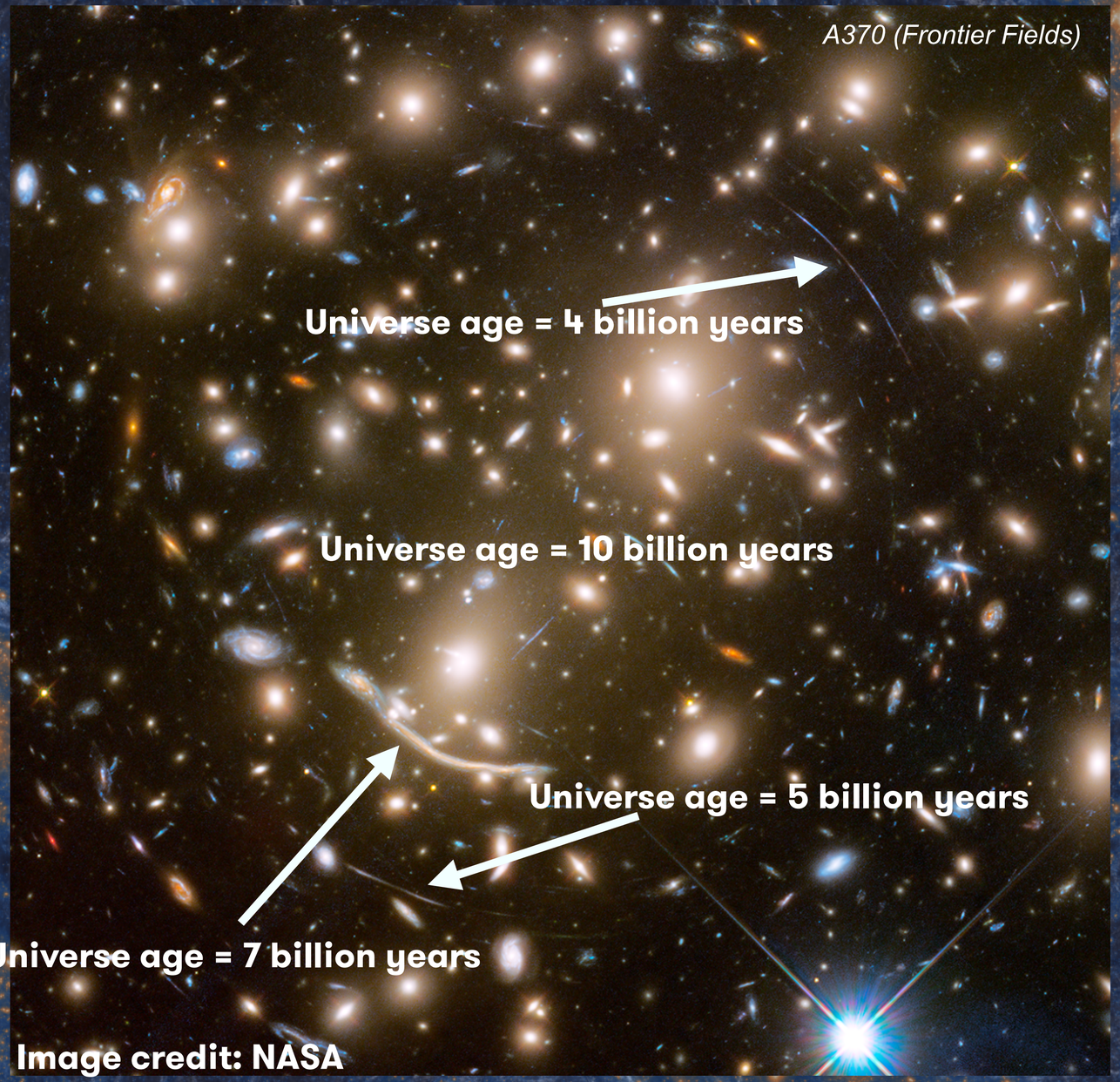

A370 (Frontier Fields)
Image credit: NASA

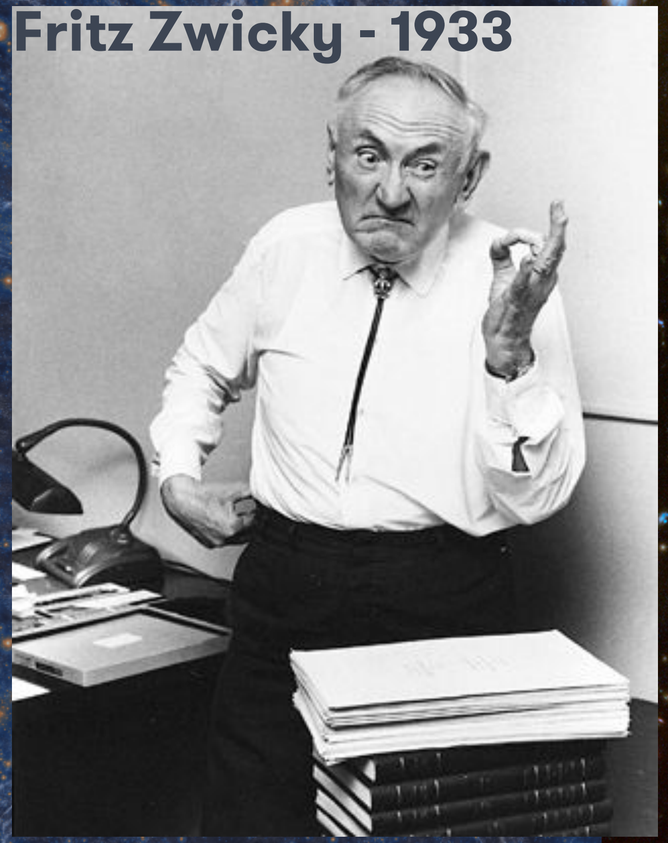

A370 (Frontier Fields)
Image credit: NASA

# Gravitational Lensing




## Galaxy clusters can be used as space telescopes

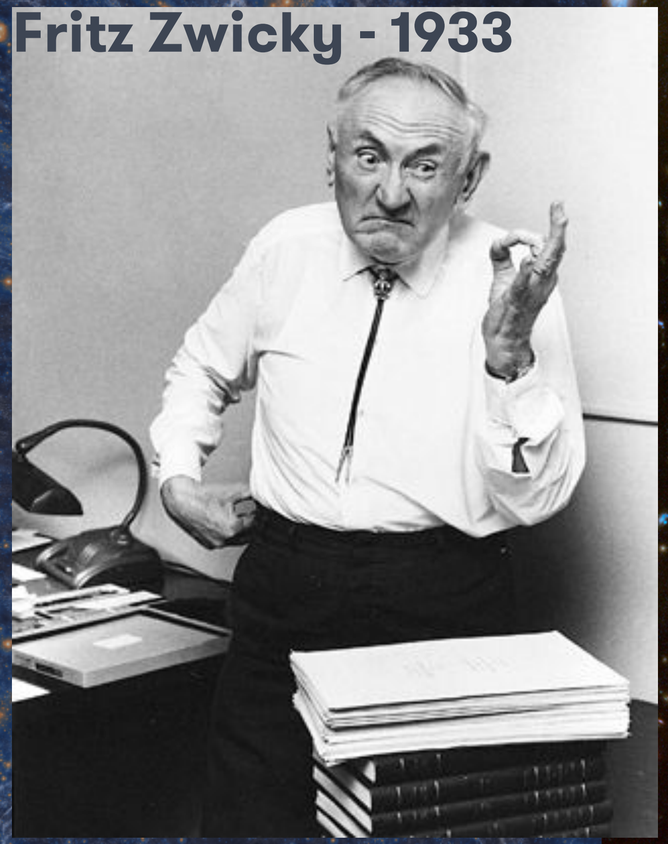

A370 (Frontier Fields)
Universe age = 4 billion years
Universe age = 10 billion years
Universe age = 5 billion years
Universe age = 7 billion years
Image credit: NASA


Fritz Zwicky - 1933


A370 (Frontier Fields)

Materia oscura

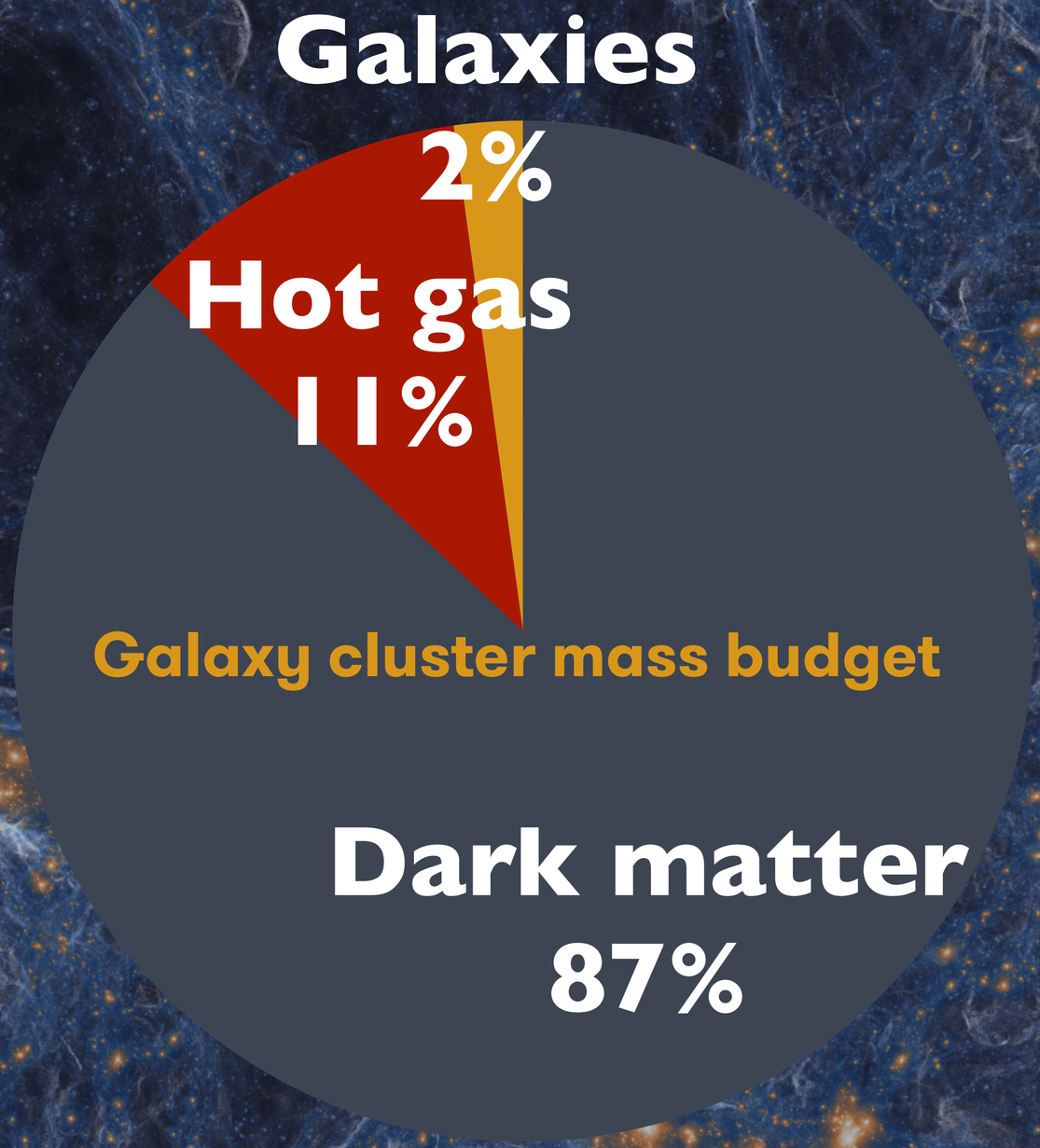
Σκοτεινή ύλη



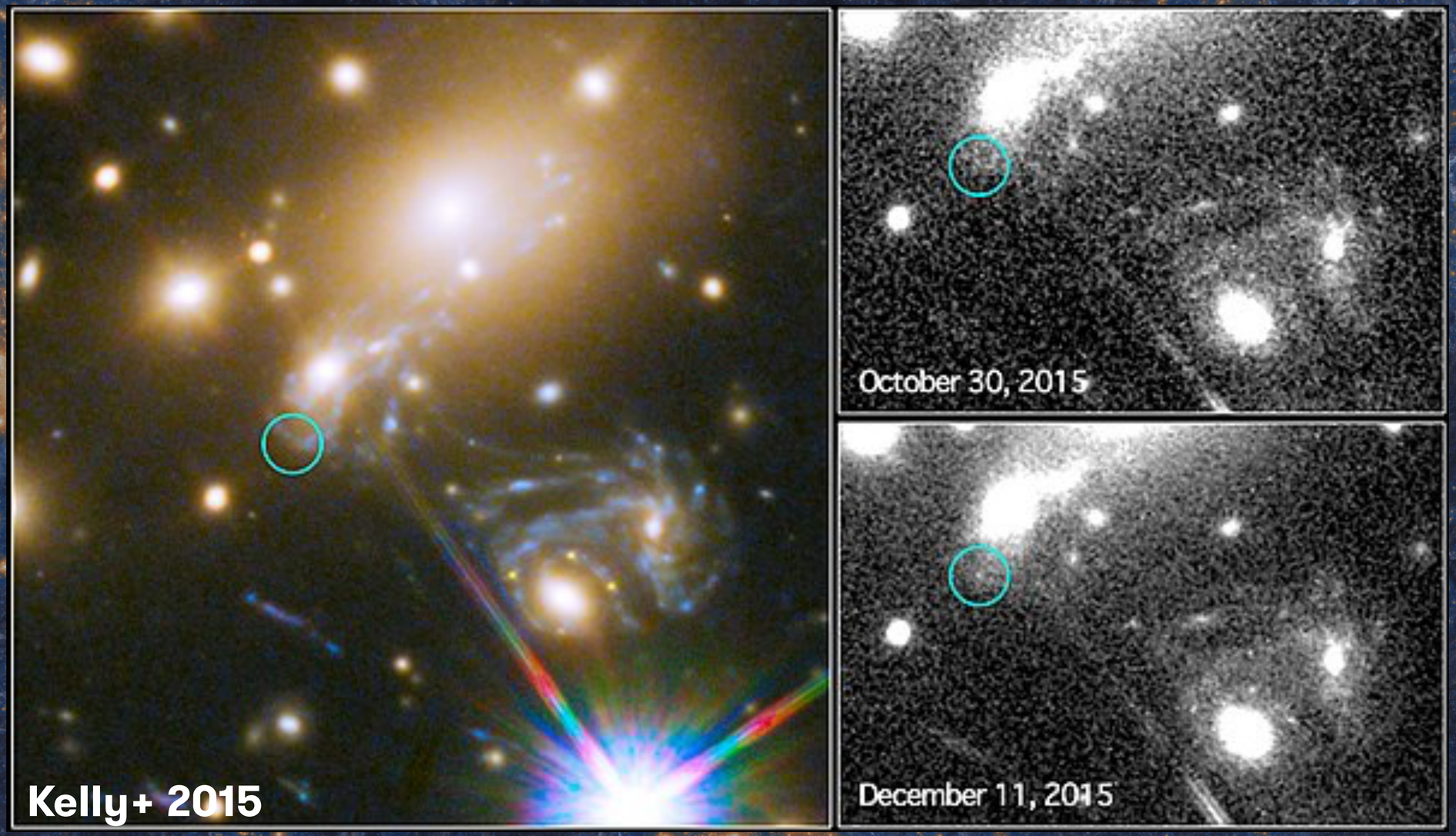


Matière noire

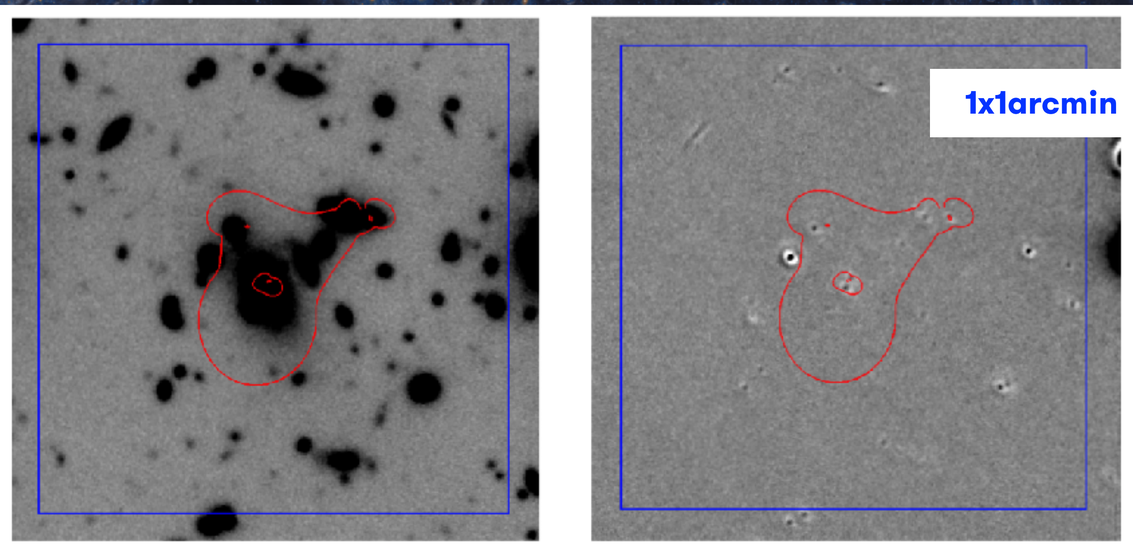
Dunkle Materie


Galaxies
2%
Hot gas
11%
Galaxy cluster mass budget
Dark matter
87%

# Predicting Supernova appearance

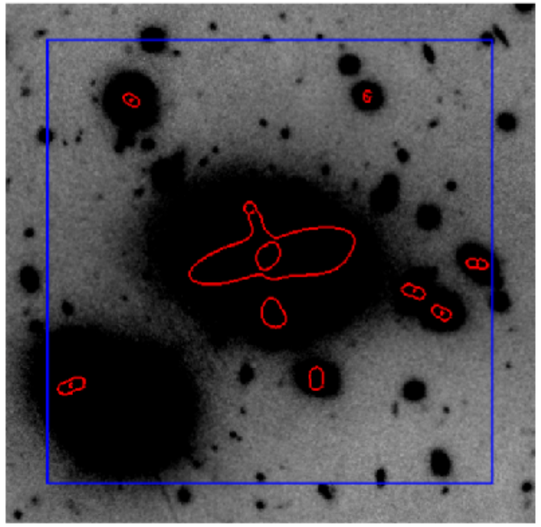


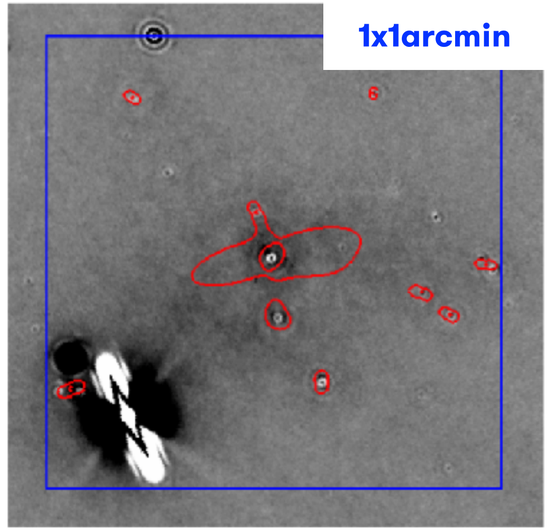
# Gravitational lensing of gravitational waves






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:
  Benchmark for cosmological models
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**LoCuSS Survey**

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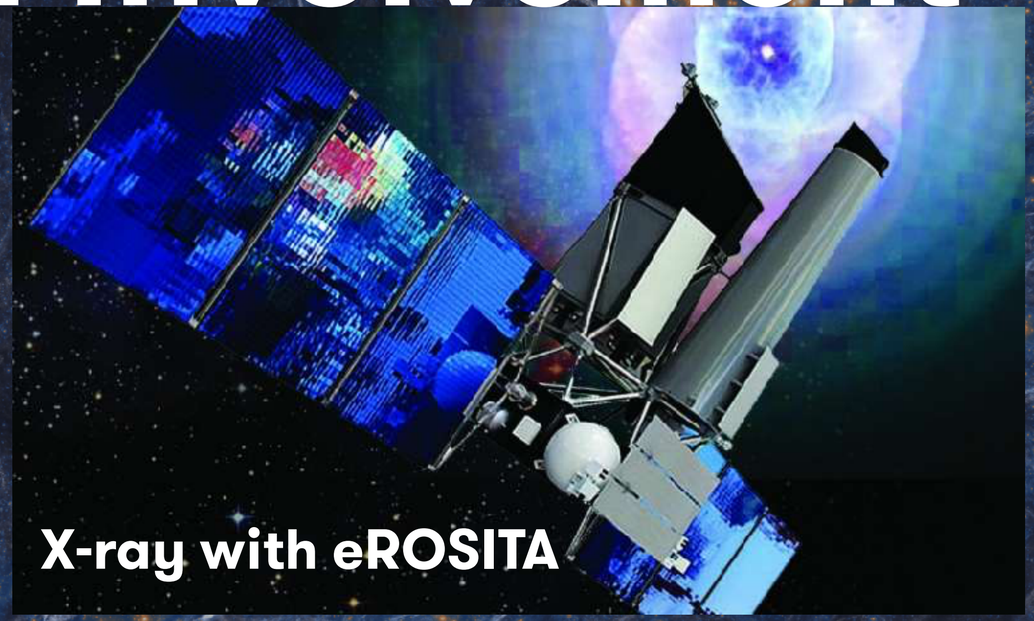
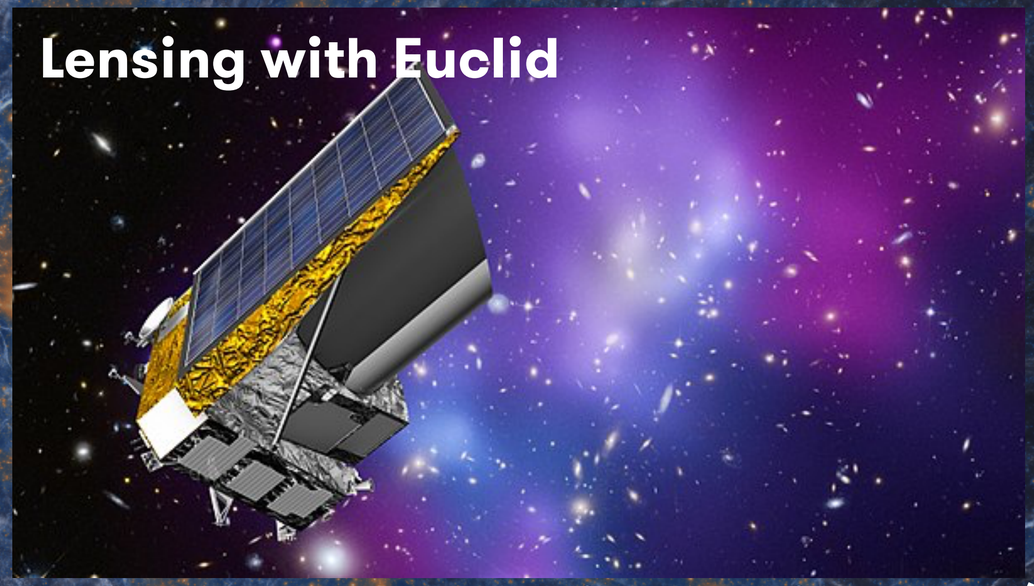
# Birmingham involvement

Galaxy evolution with LSST



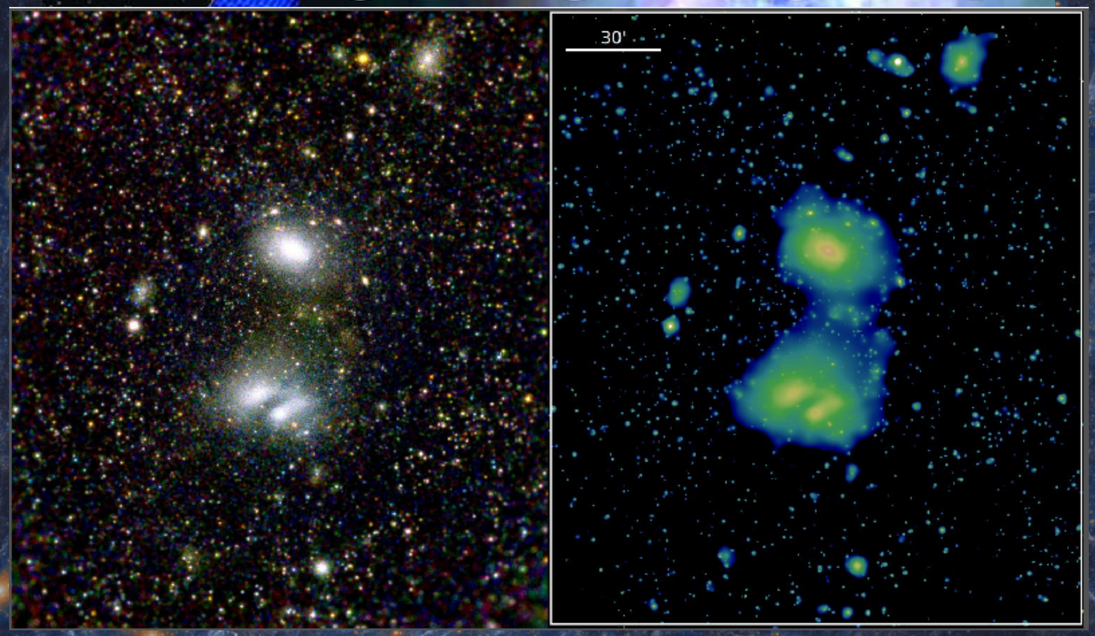
X-ray with eROSITA

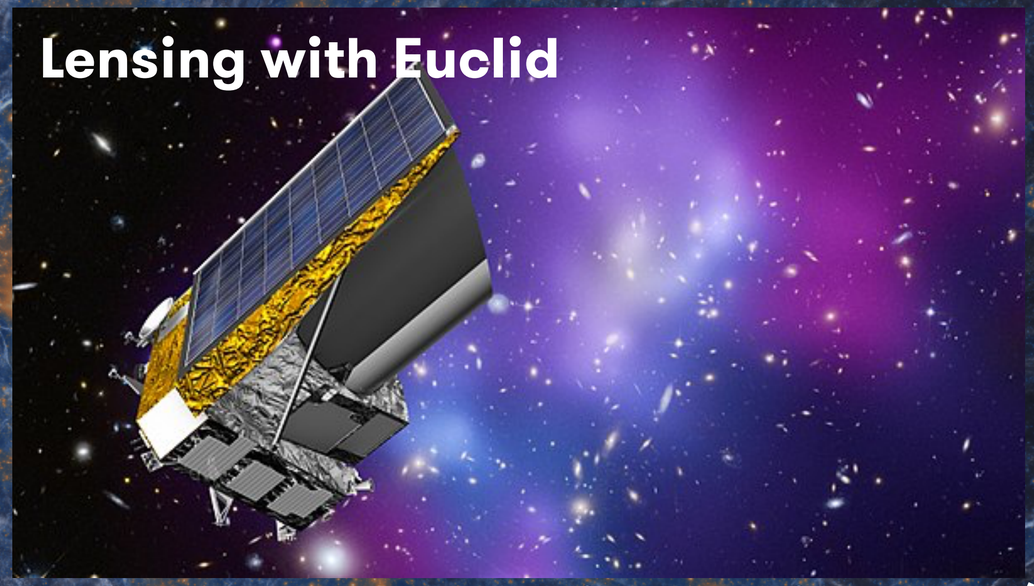


Lensing with Euclid

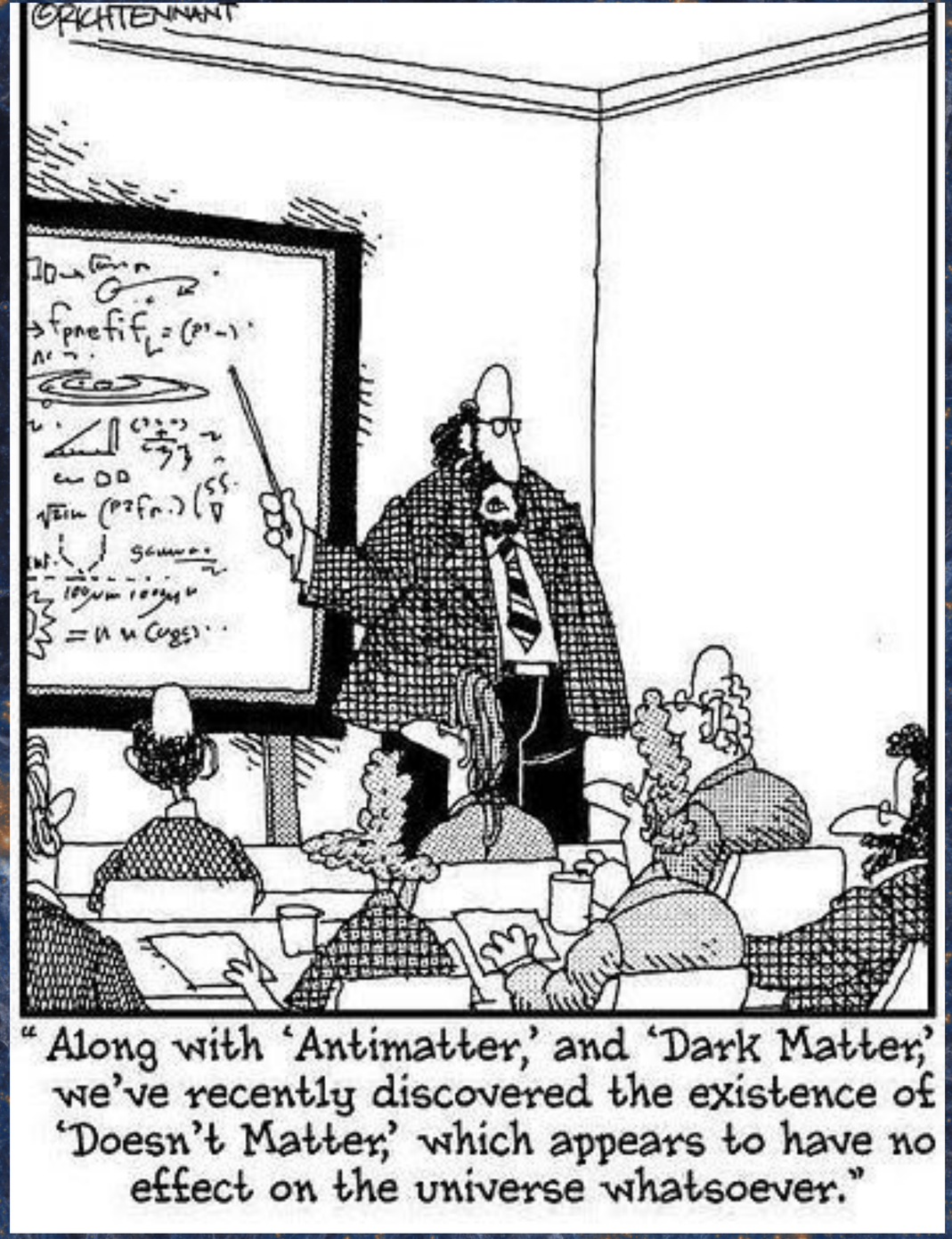
# Birmingham involvement

Galaxy evolution with LSST



Lensing with Euclid

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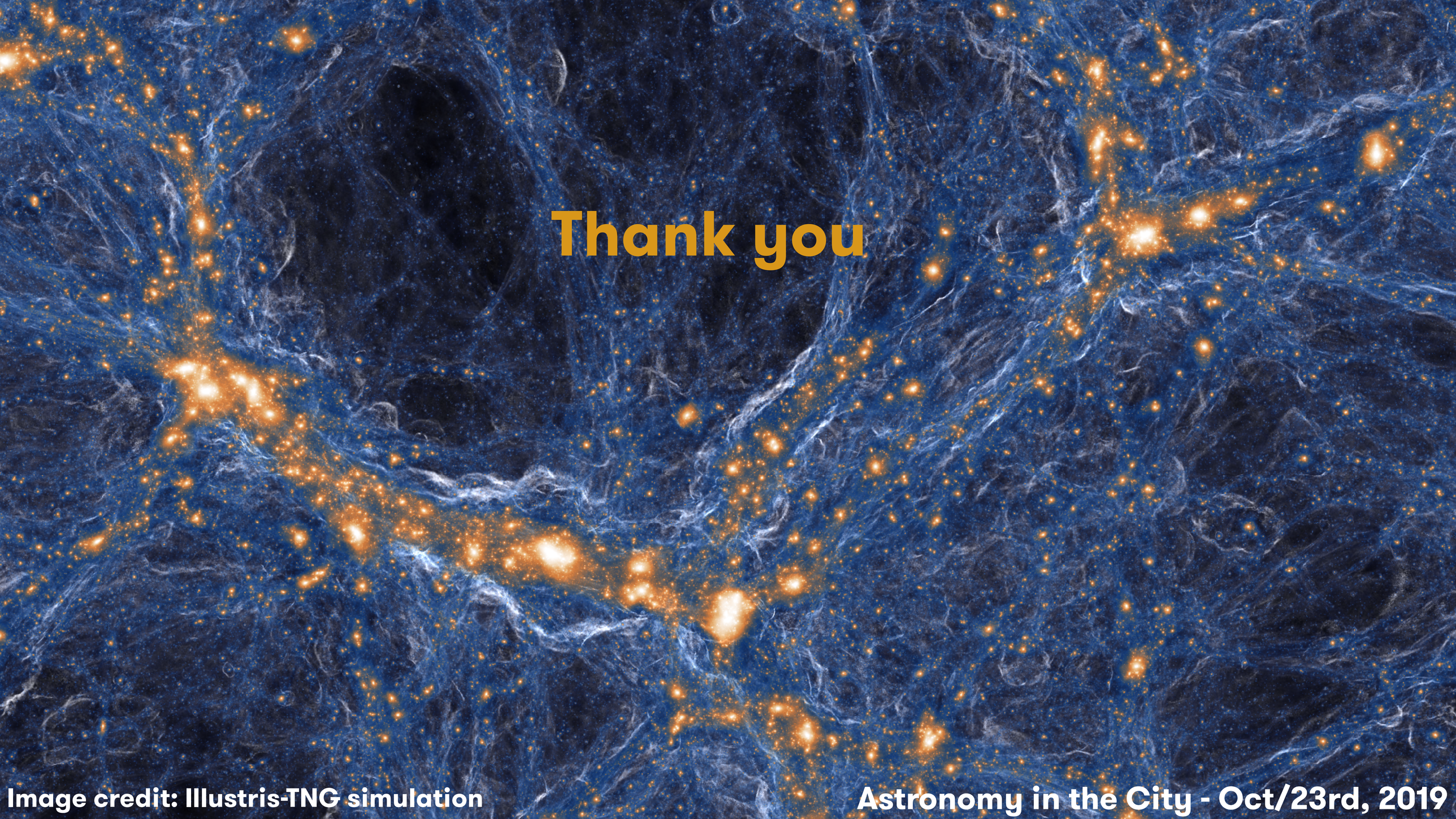


Image credit: Illustris-TNG simulation