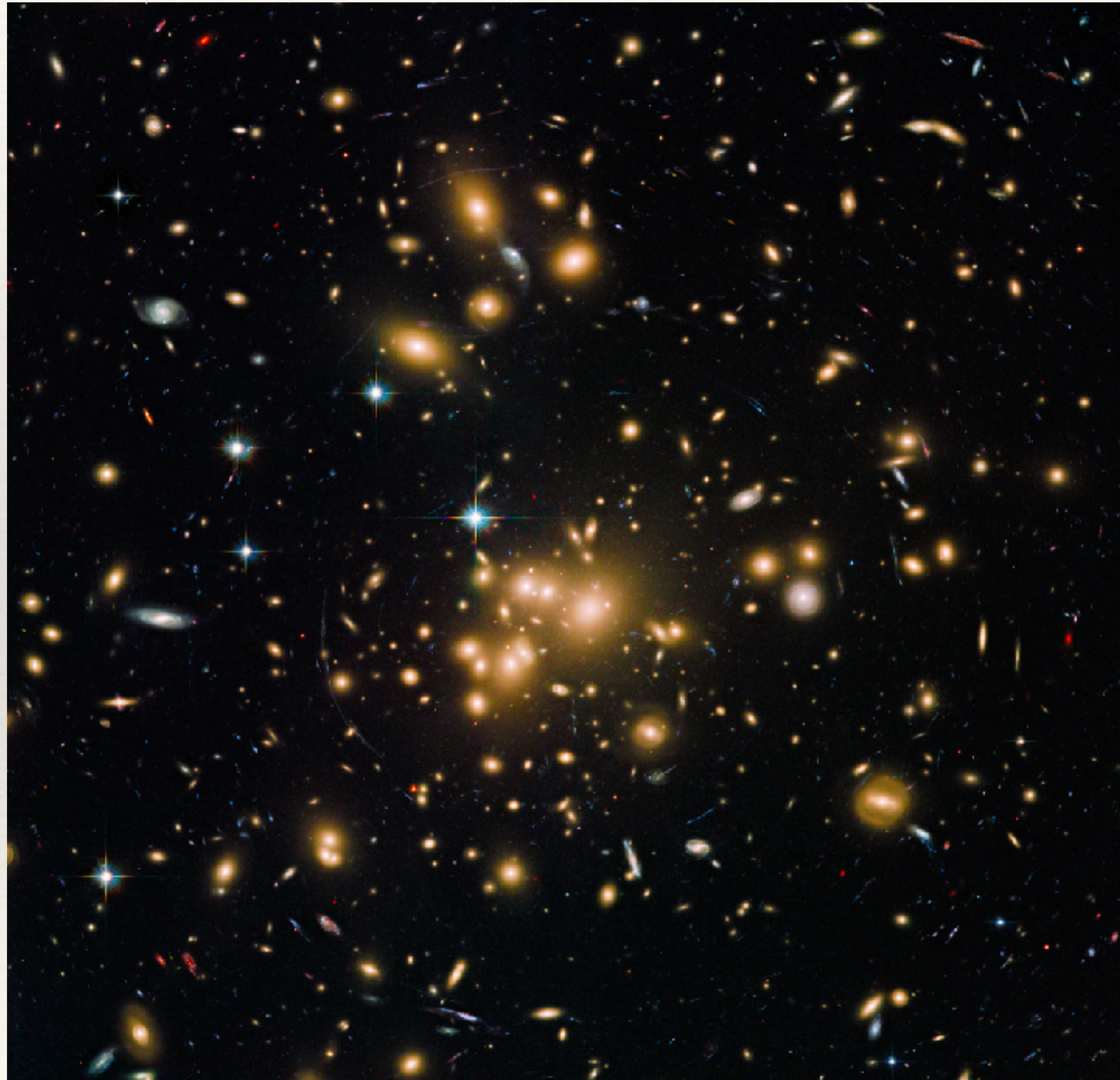


Galaxy Clusters: Giants in the Universe



Heidi Wu

Southern Methodist University



There are rich, invisible giants in the sky*!

* inspired by Dr. Anja von der Linden and “Jack and the Beanstalk”

1780s: Hunting for “nebulae” (Messier & Herschel)



Virgo Cluster



Coma Cluster

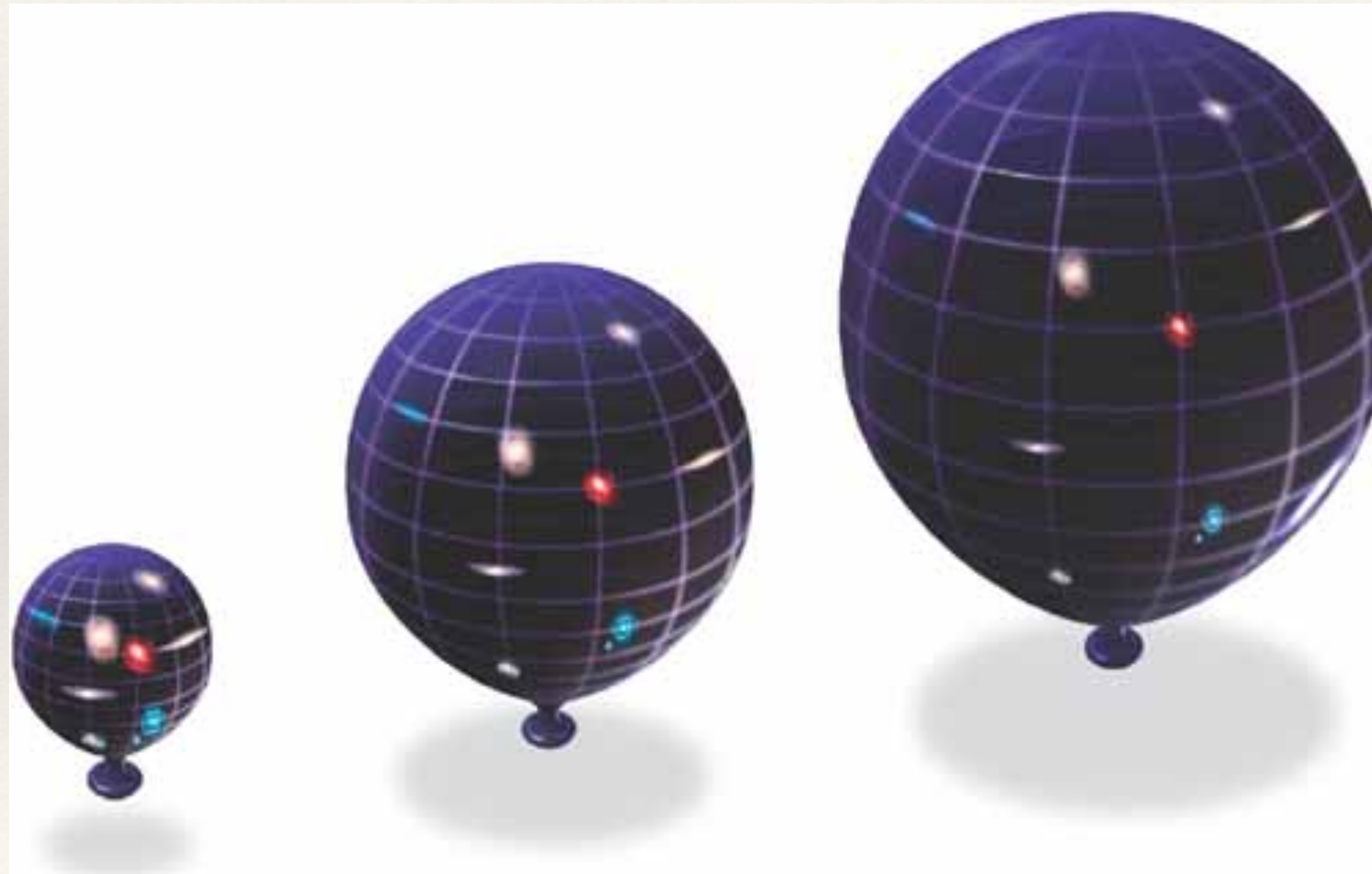
1920: The Great Debate (Shapley vs. Curtis)



Hubble (1924) found that M31 is outside the Milky Way.

1930s: The Universe is expanding

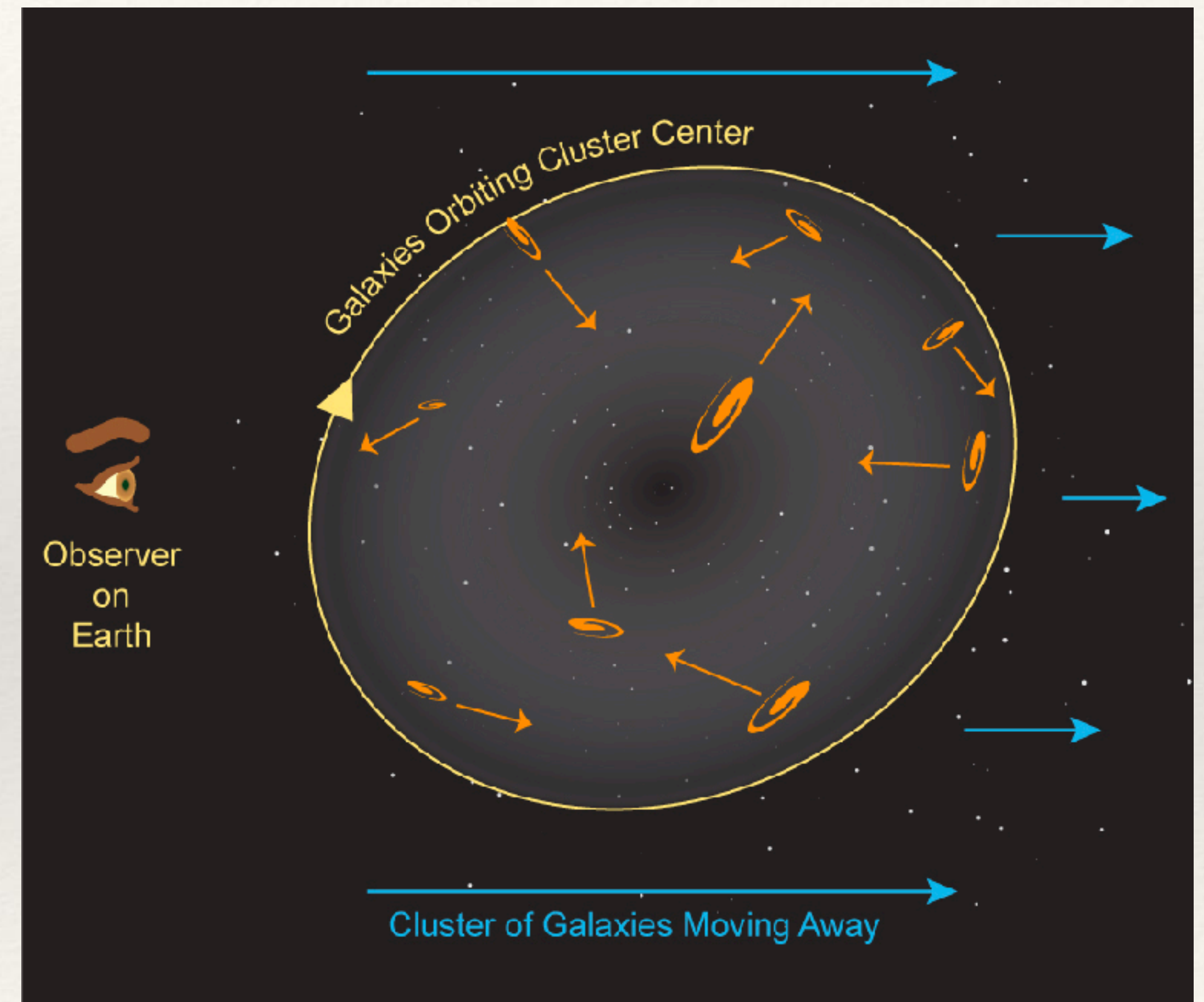
(Slipher, Hubble, Humason, Lemaitre, and Friedmann)



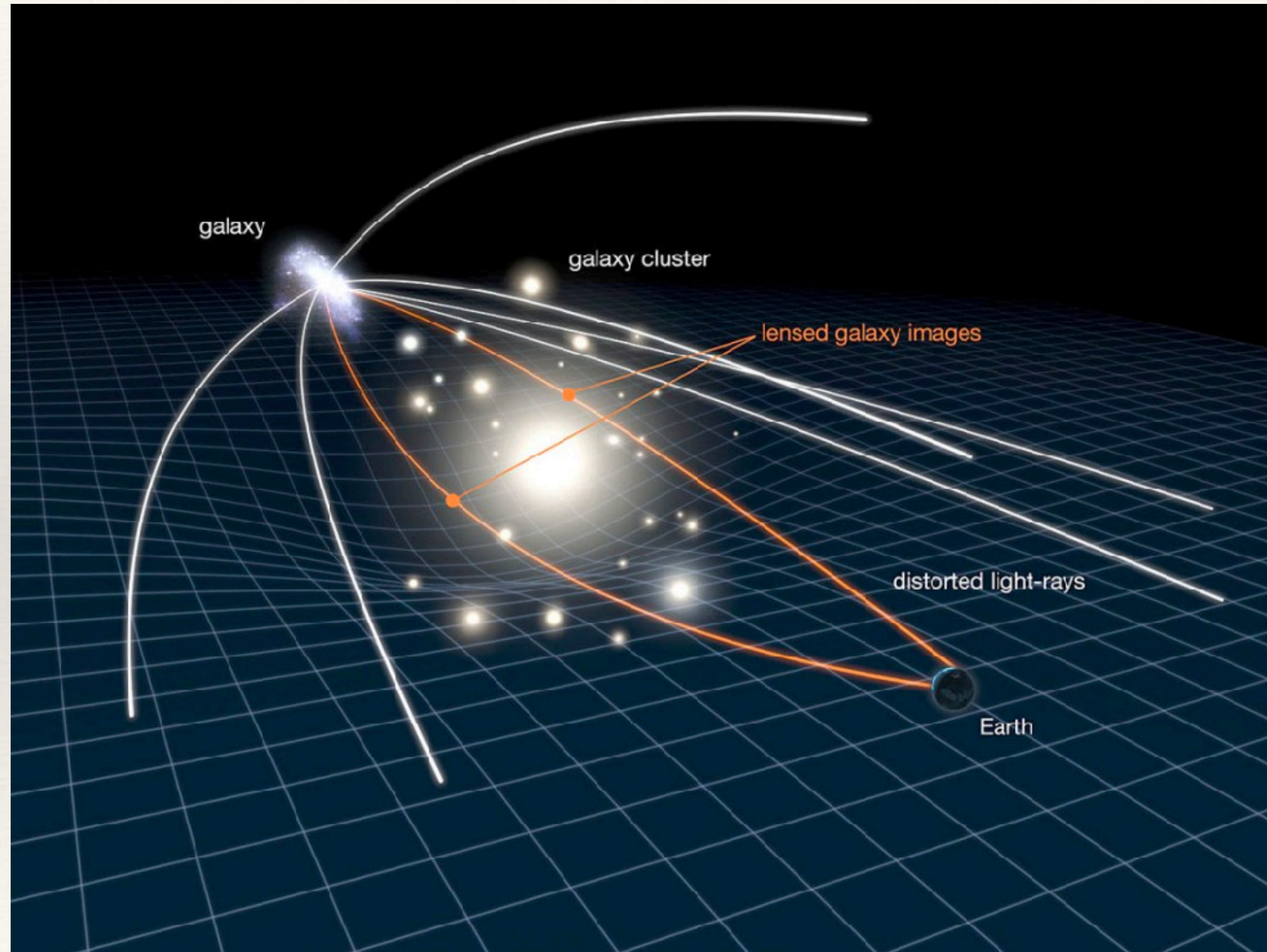
1930s: Theory of Dark Matter (Zwicky)



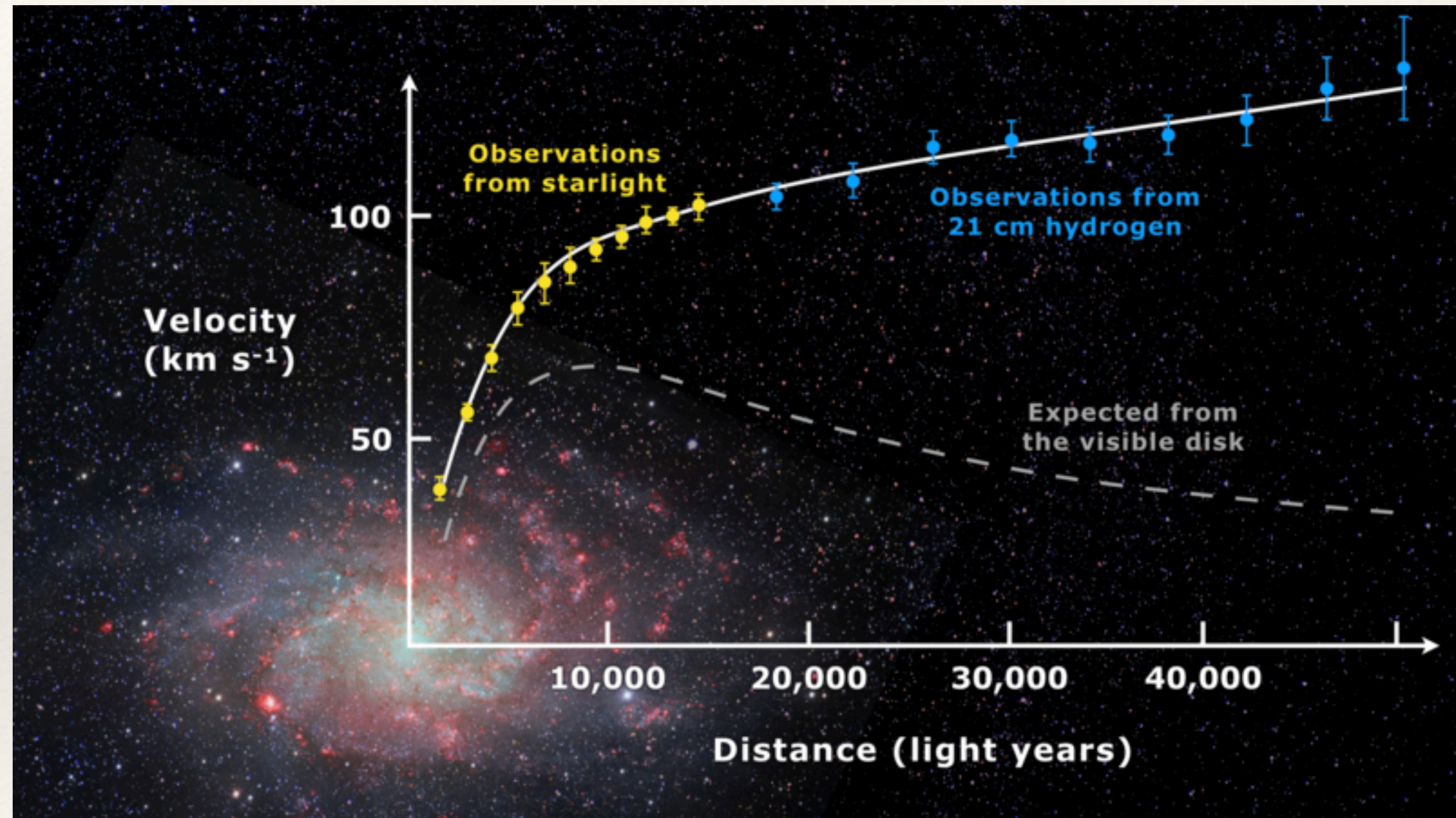
Coma Cluster



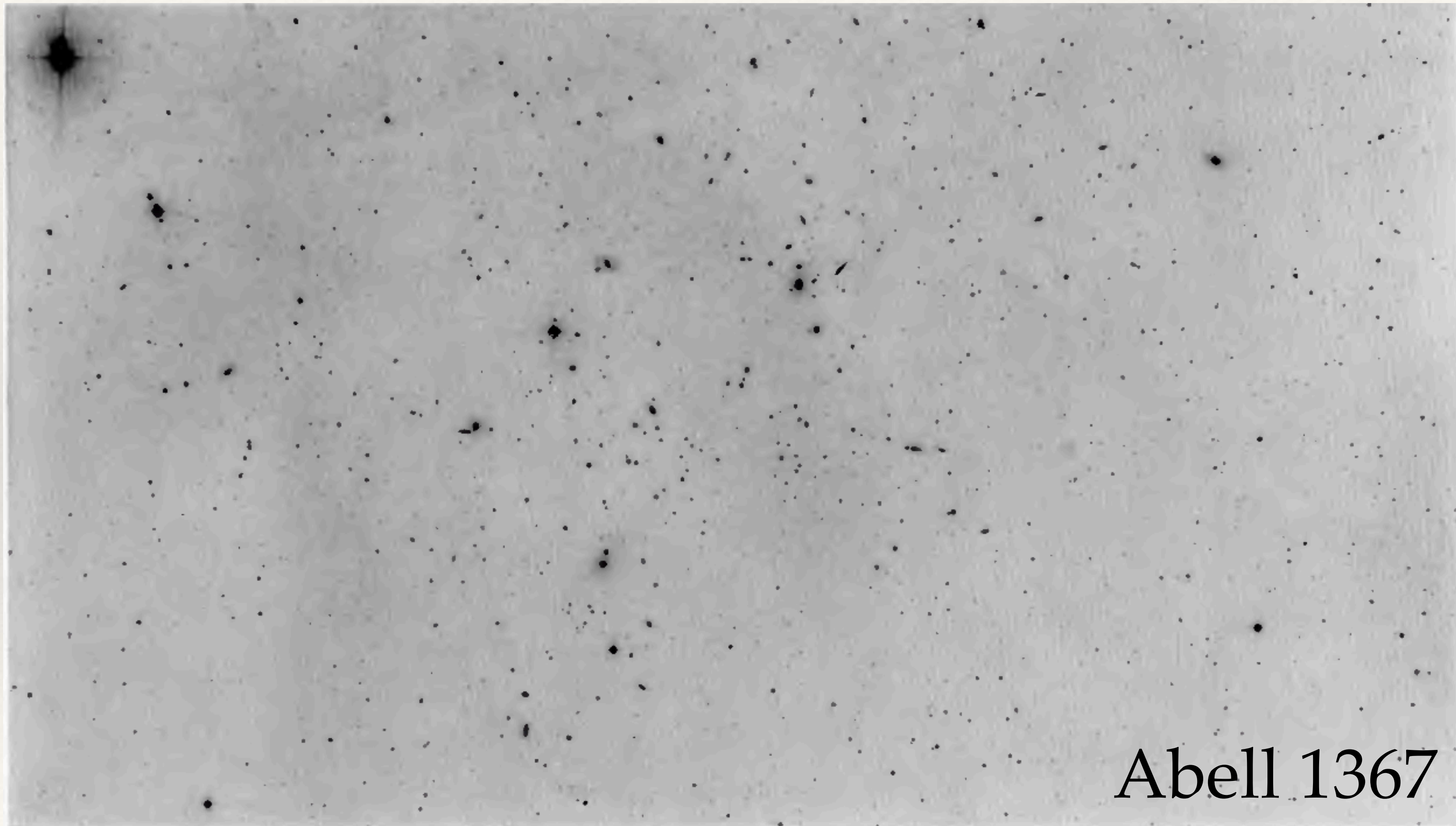
1930s: Theory of gravitational lensing from clusters (Zwicky)



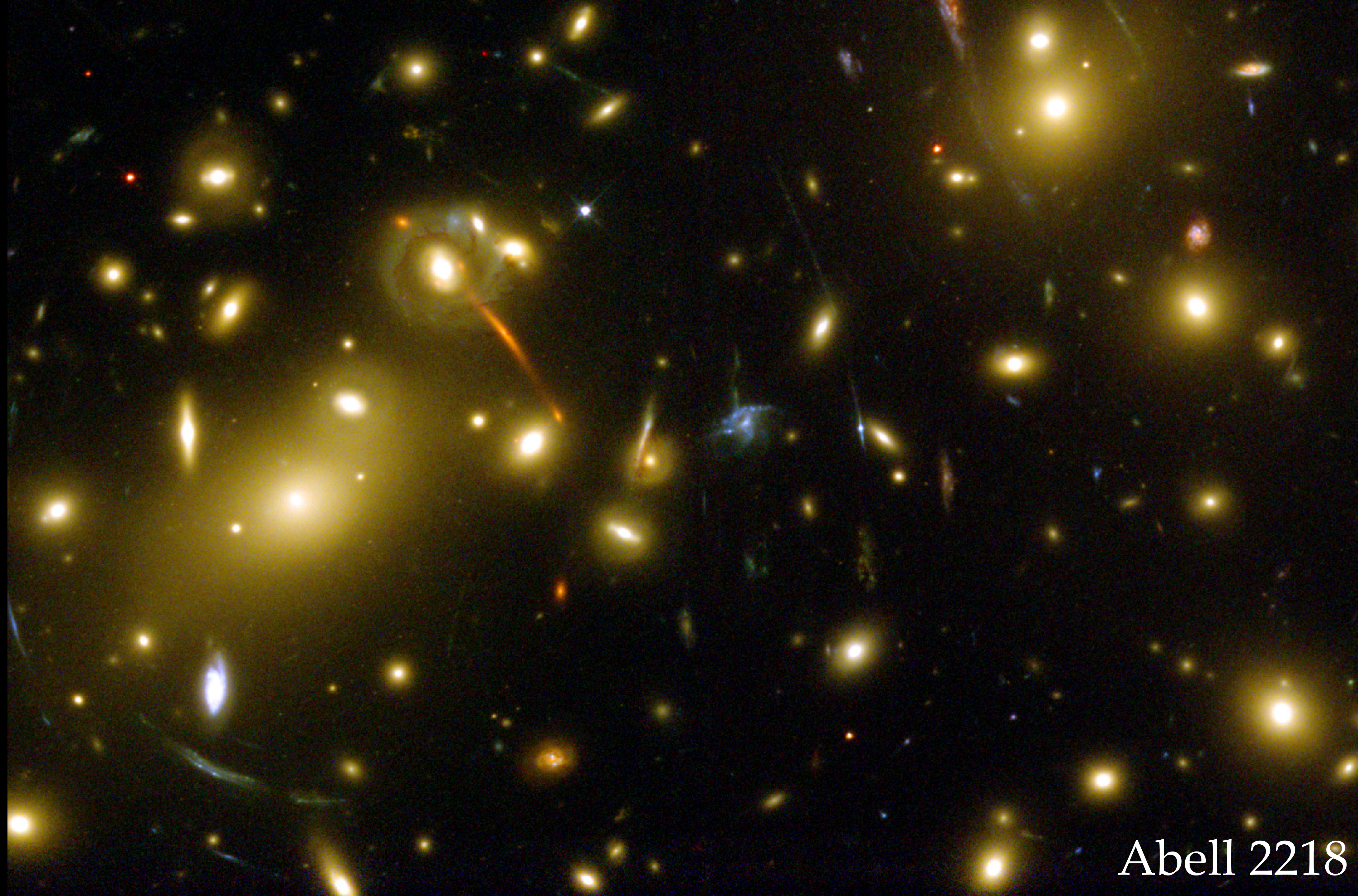
1960: Evidence of Dark Matter (Vera Rubin)



1958: First galaxy cluster catalog (Abell catalog)



Abell 1367



Abell 2218



Abell 1689



JWST's First
Deep Field
SMACS 0723

“Richness” of galaxy clusters (number of galaxies)



Low richness

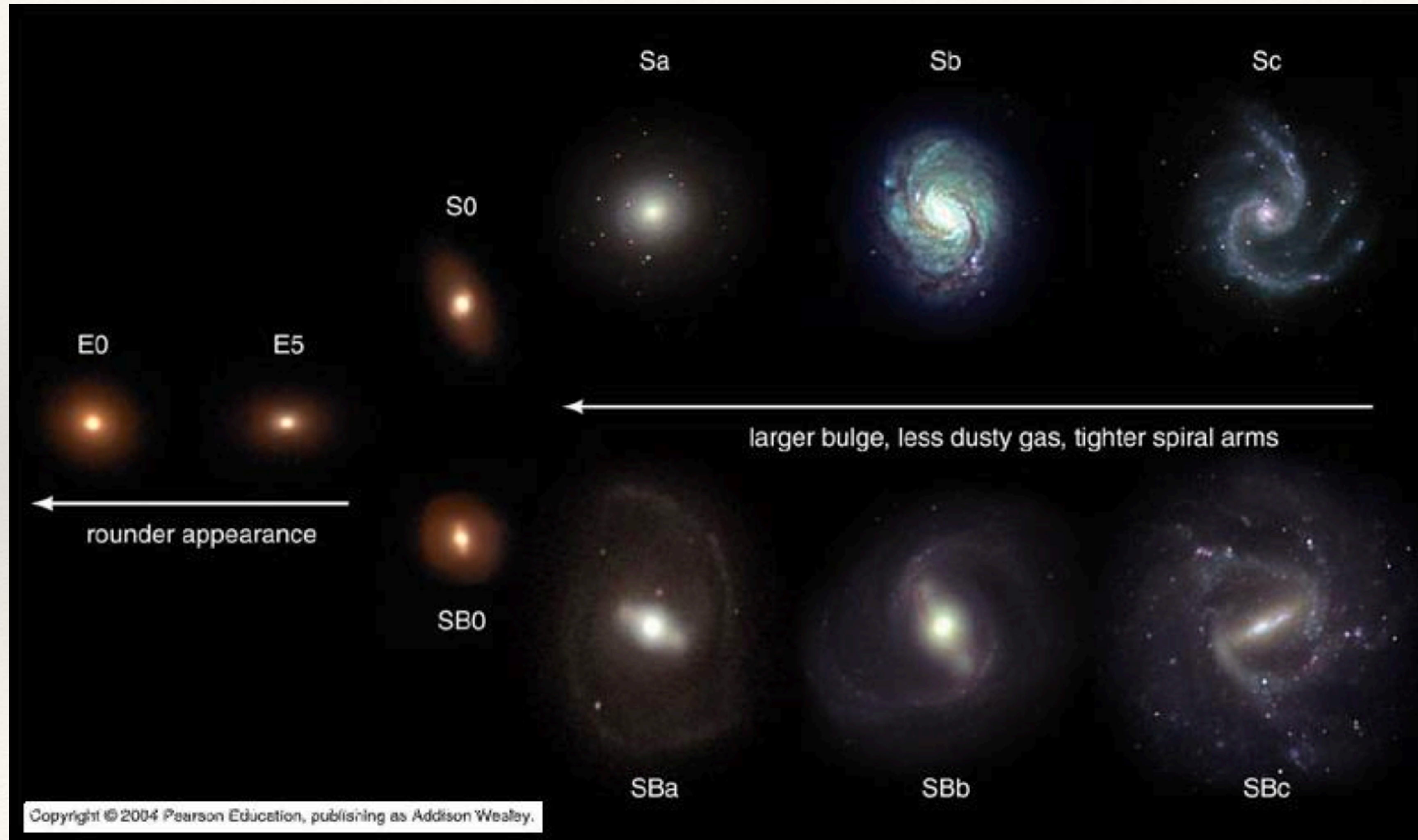
VS.



High richness

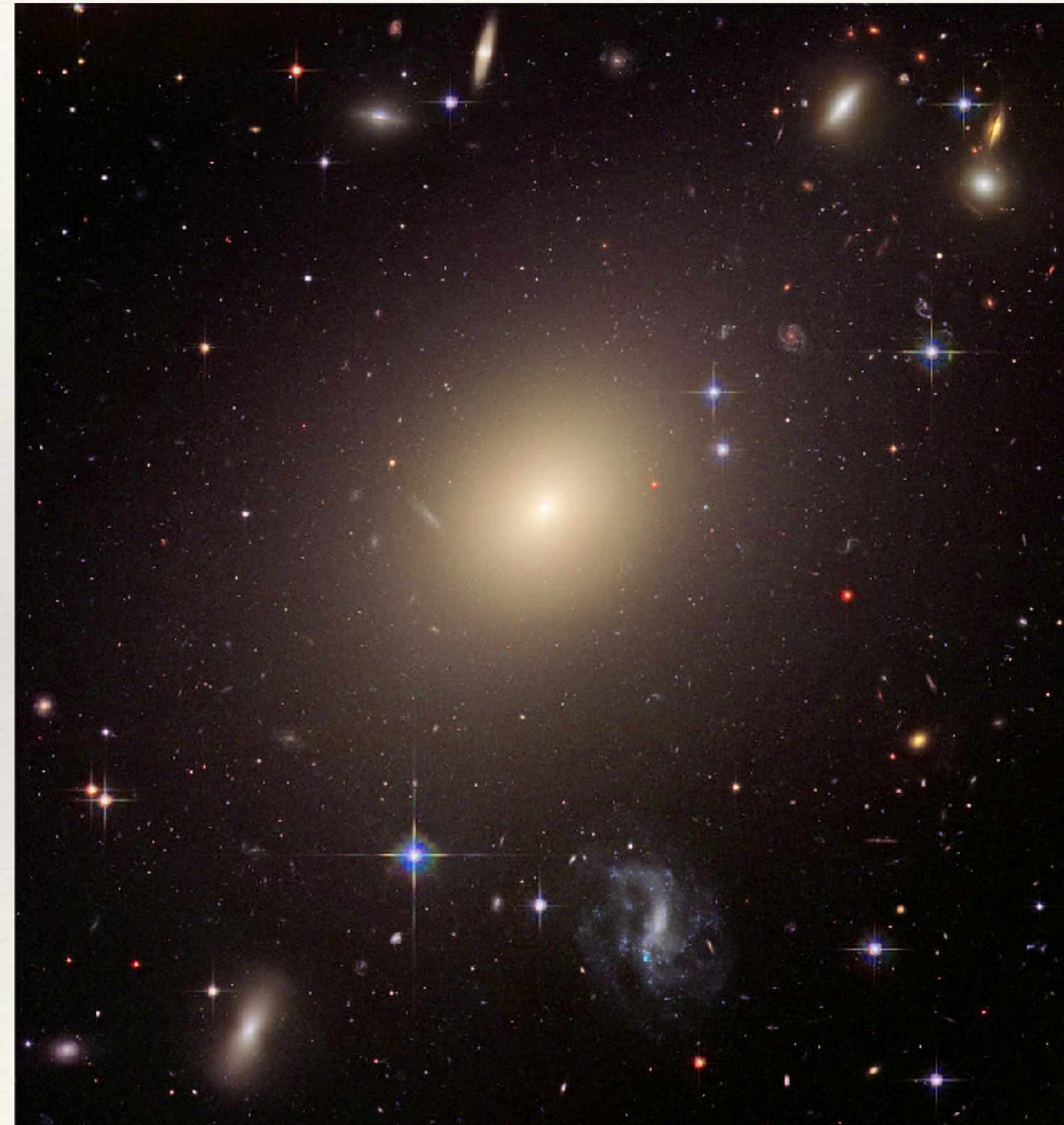
One galaxy, Two galaxy, Red galaxy, Blue galaxy

Elliptical
& red

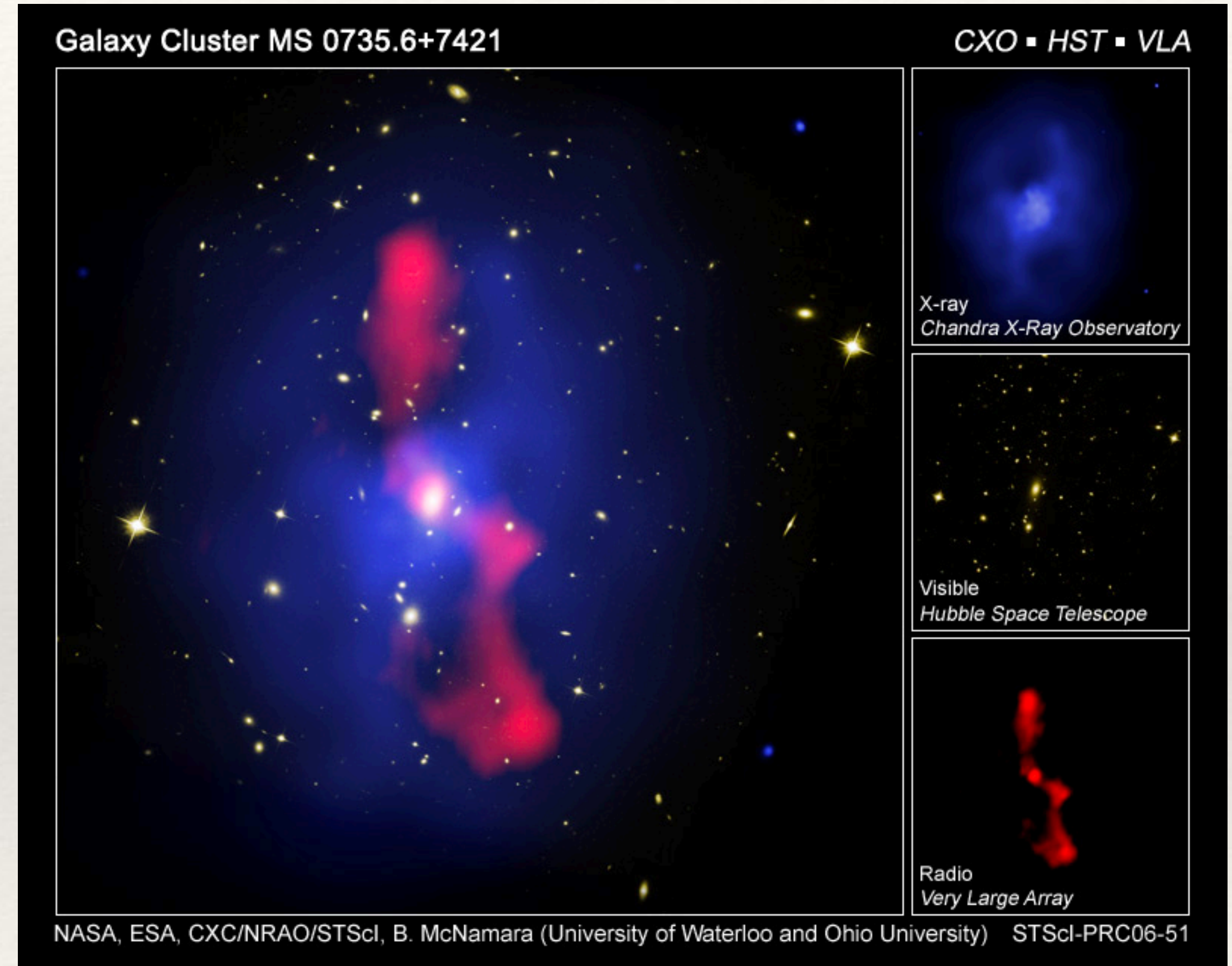
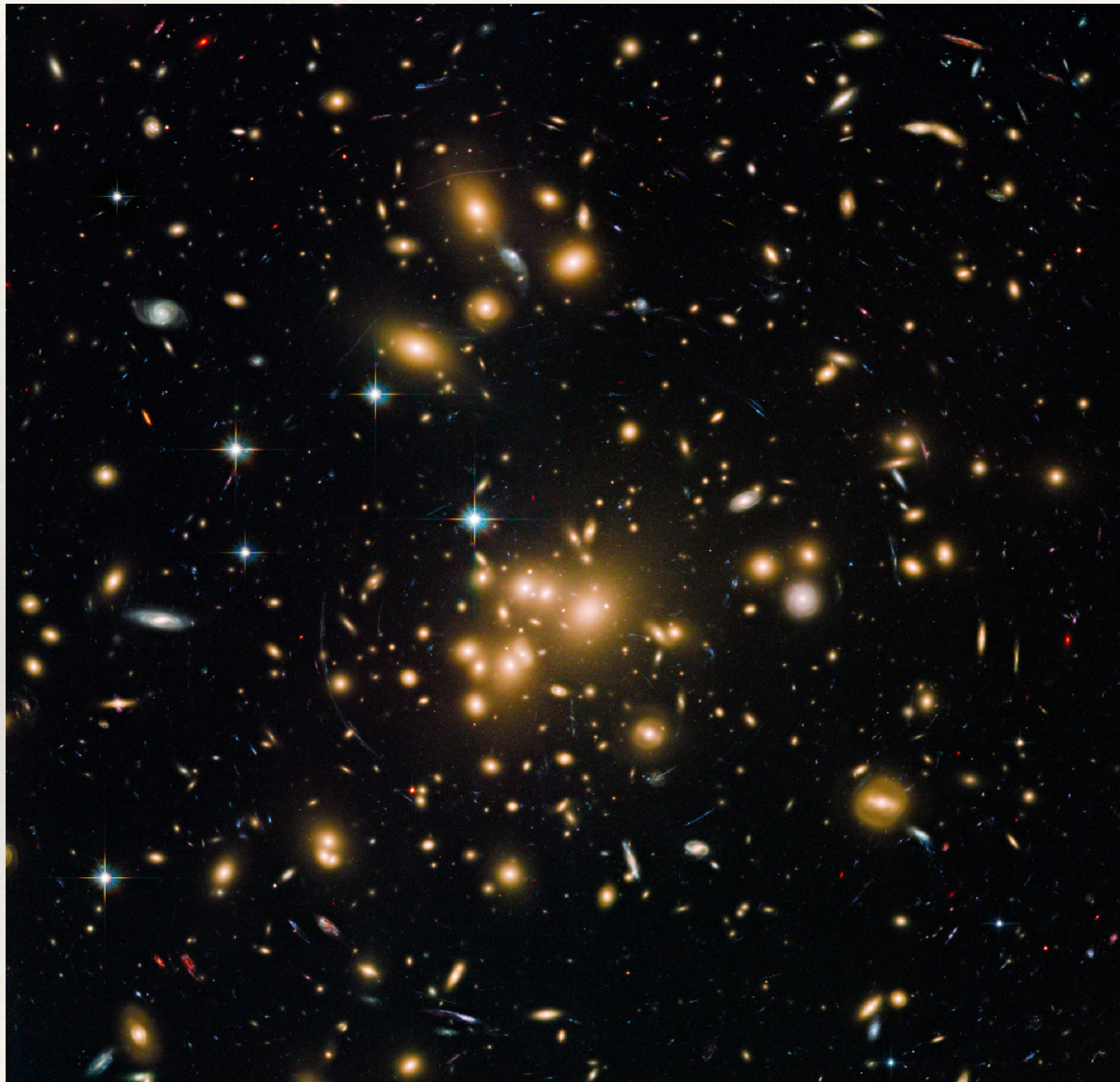


Spiral &
blue

Blue galaxies are forming stars



Most galaxies in clusters are red ellipticals

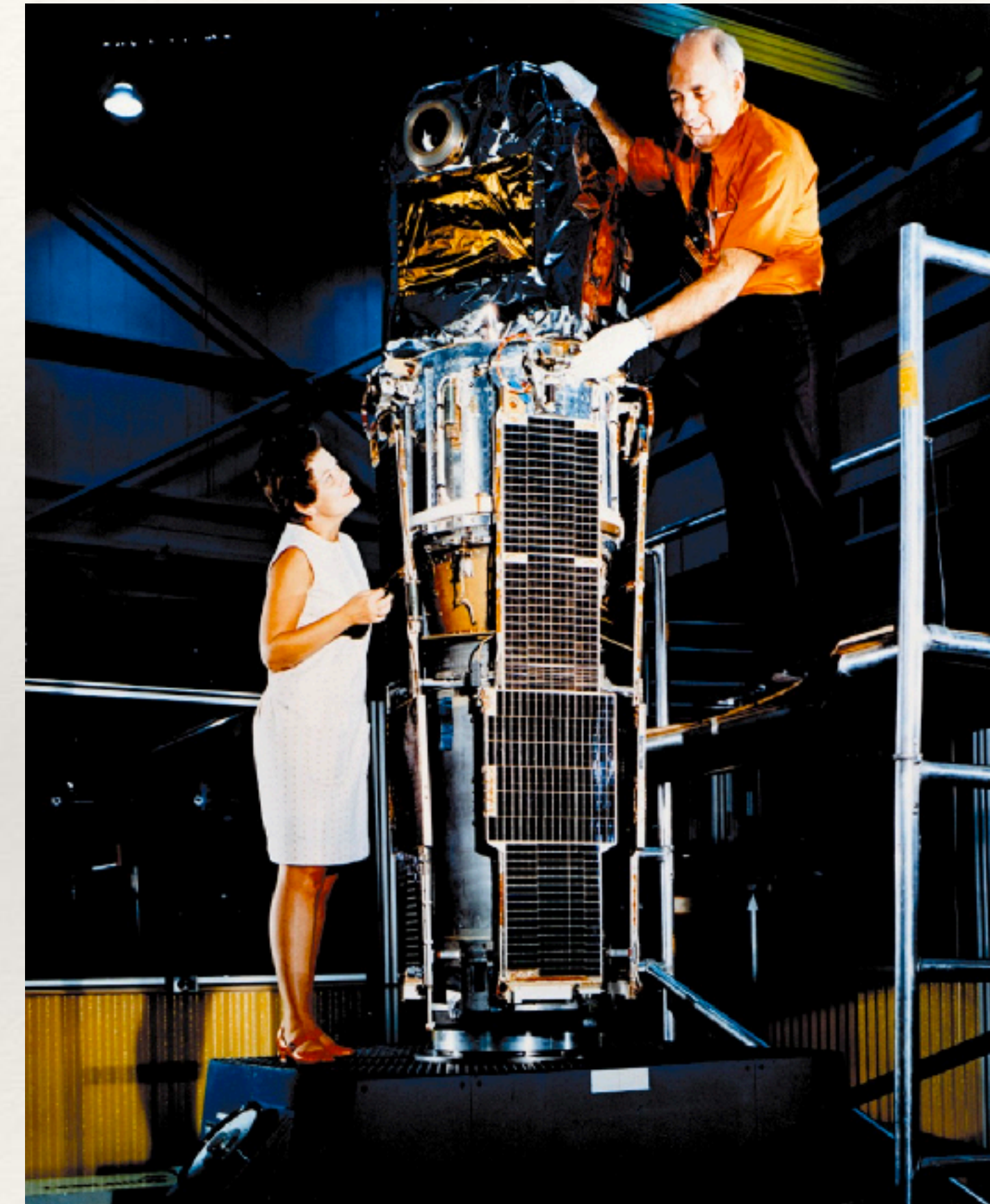


Supermassive blackhole

1970s: X-ray telescopes in space

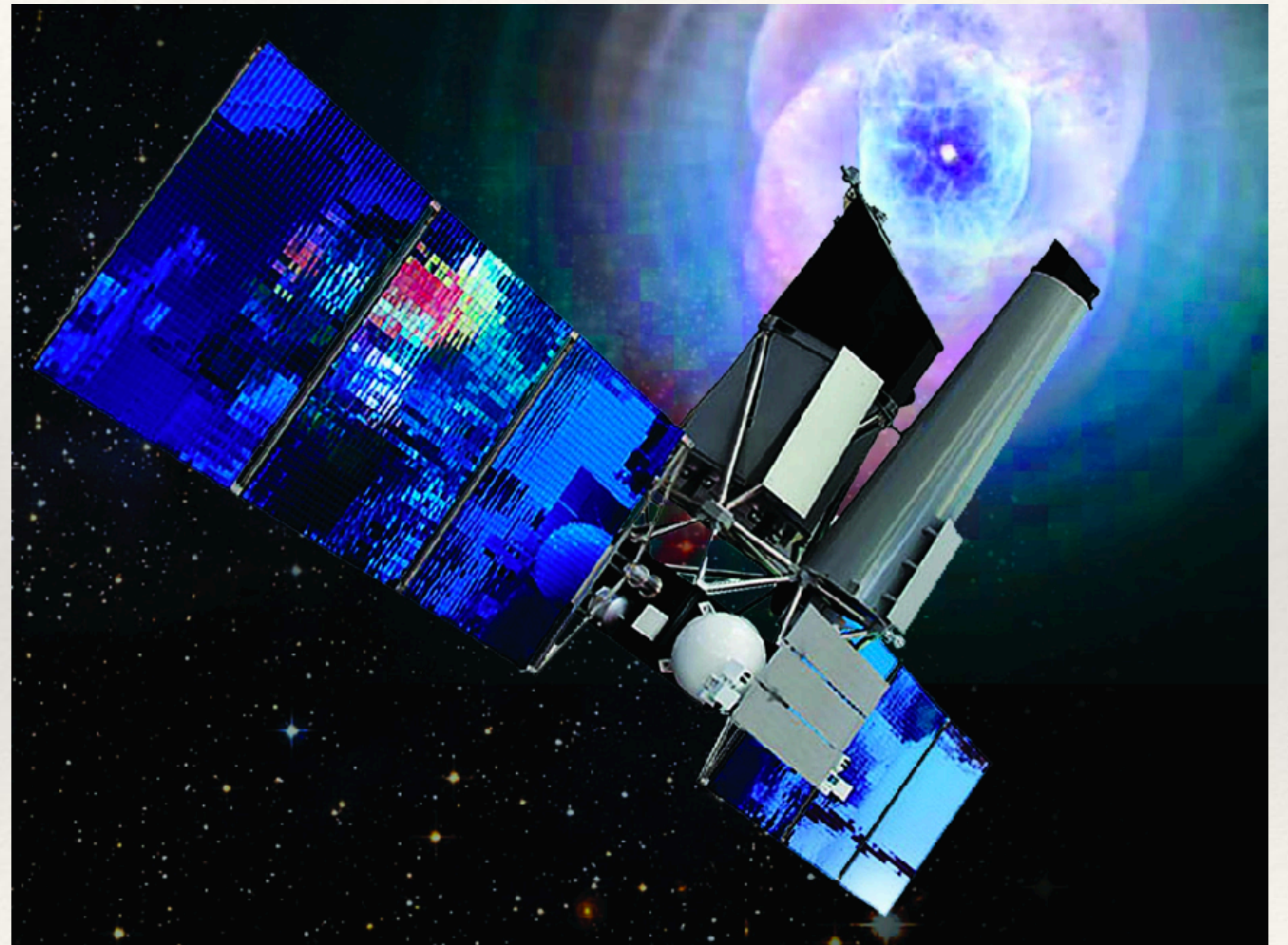


Aerobee Rocket

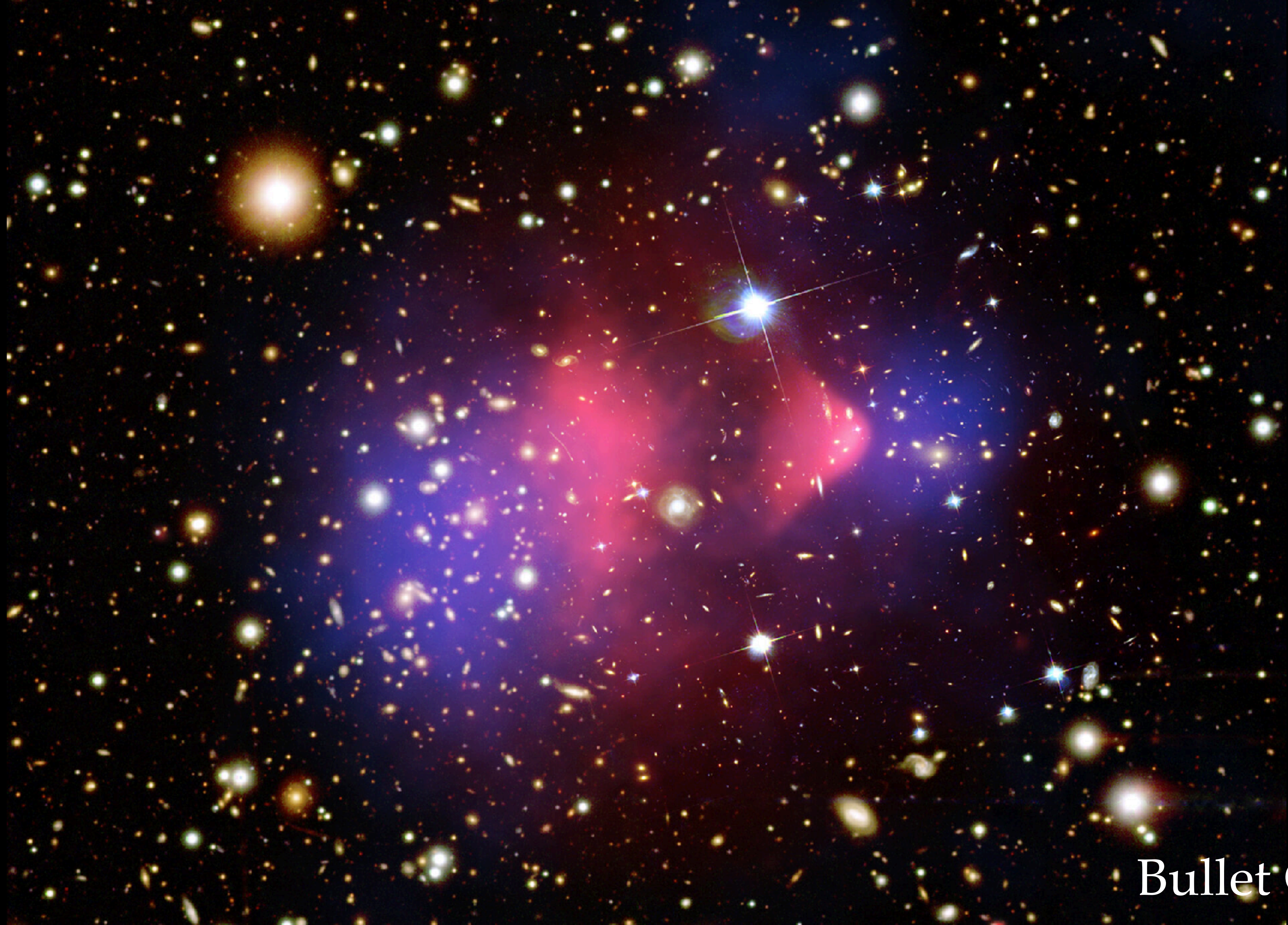


Uhuru Satellite

Hot gas in galaxy clusters emits X-ray



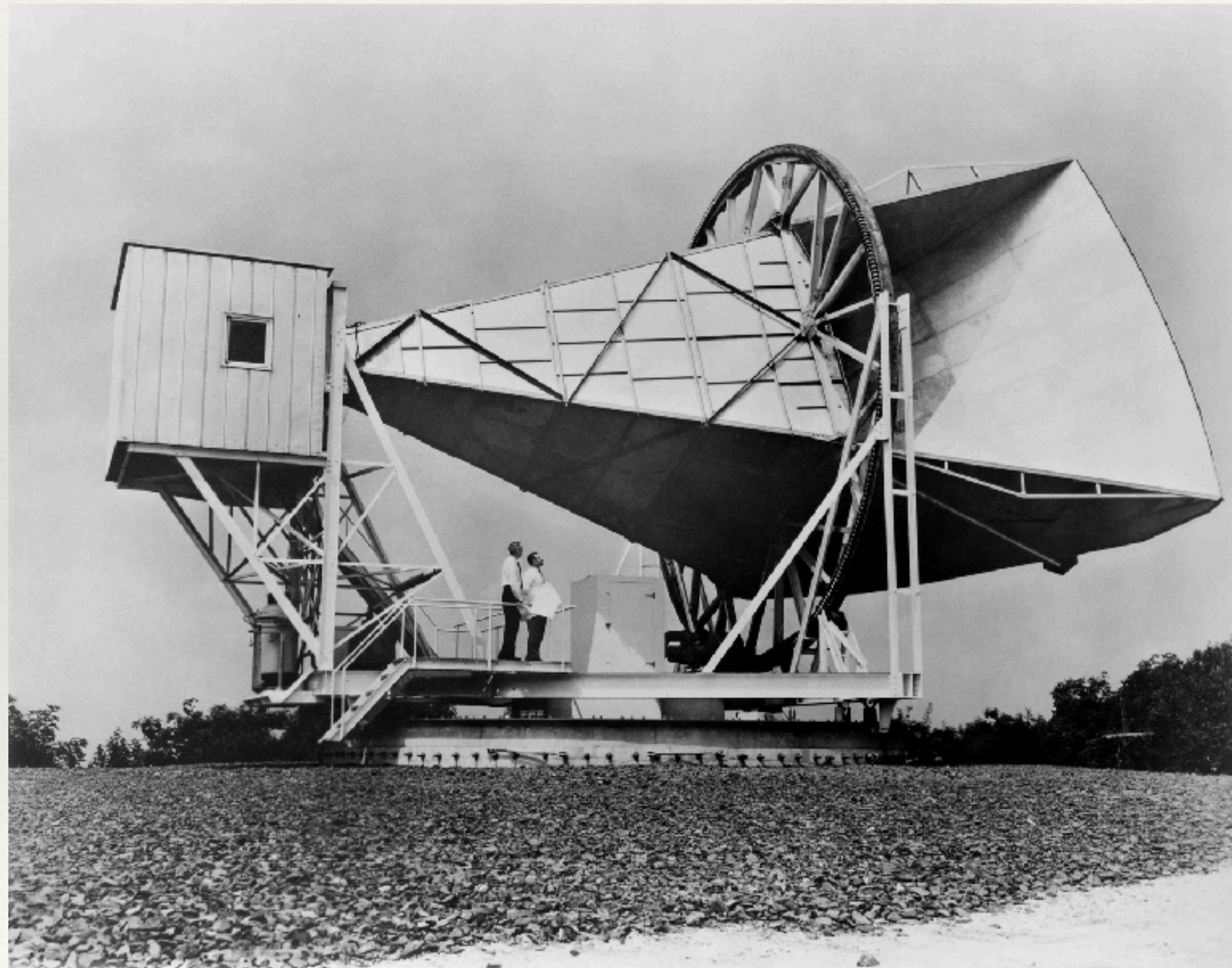
eRosita X-ray Telescope (launched 2019)



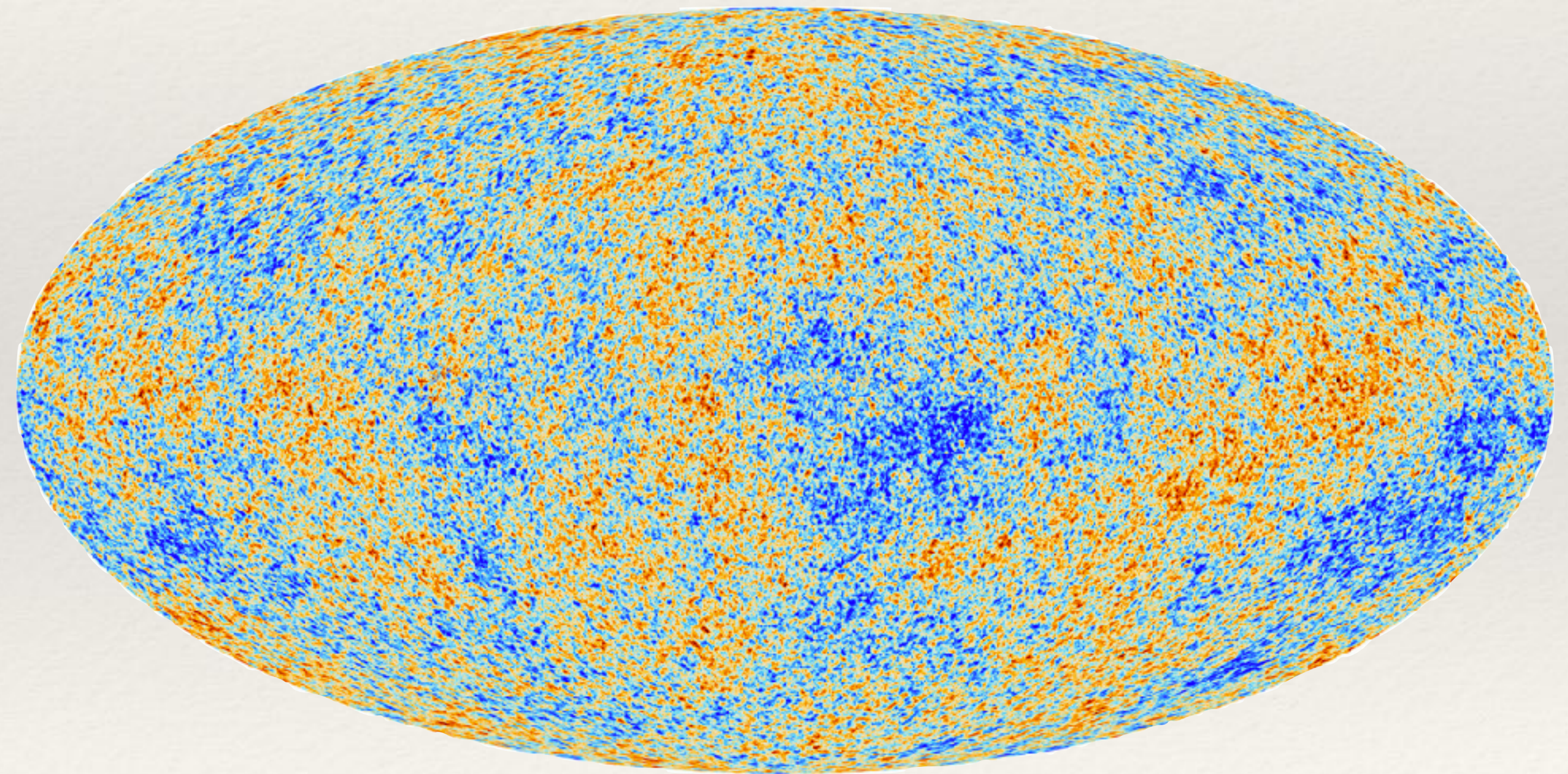
Bullet Cluster

Discovery of Cosmic Microwave Background (CMB)

Penzias and Wilson (1965)

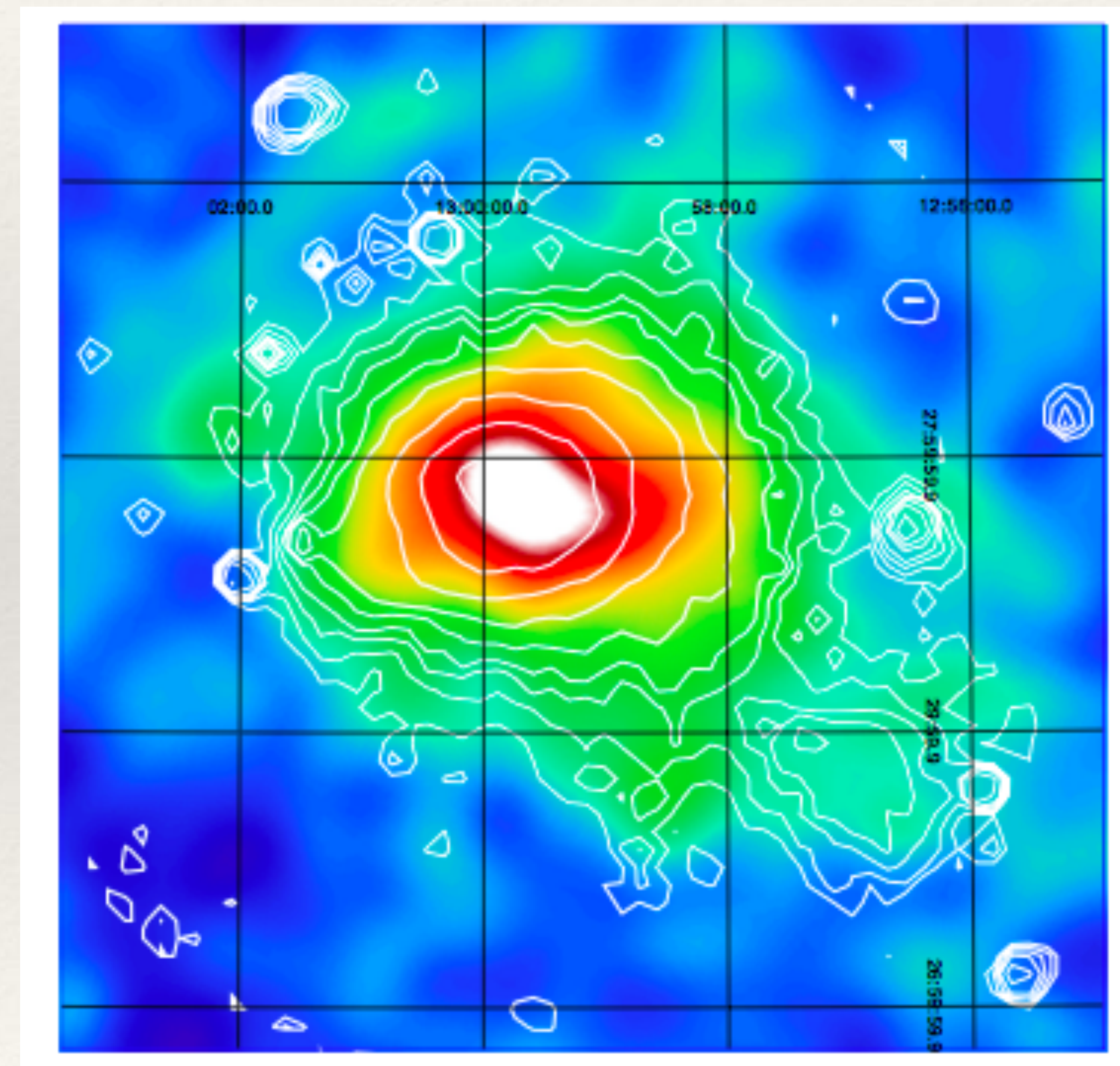
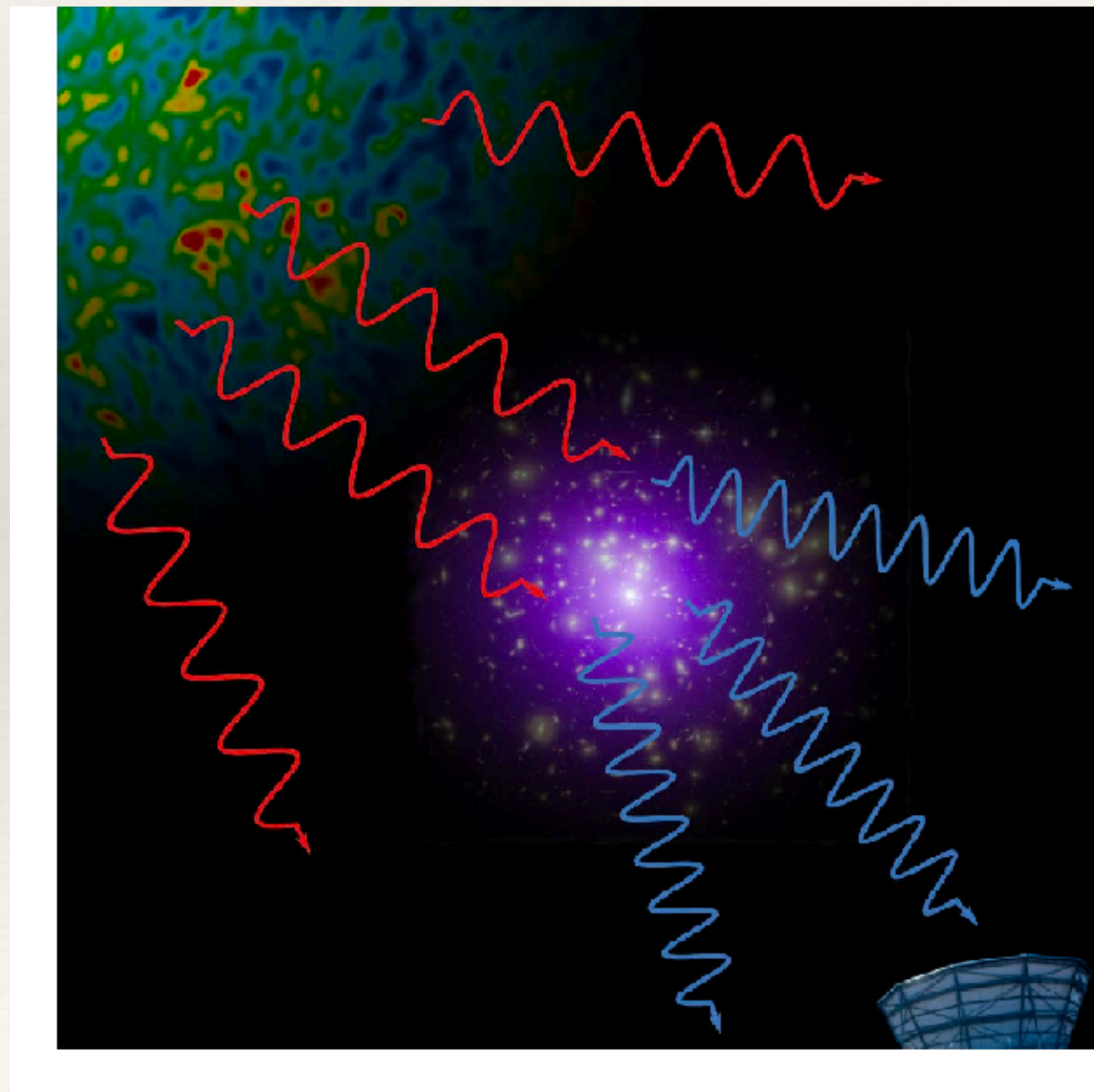


Photons of temperature 3 Kelvin (-454 Fahrenheit)



Hot gas in galaxy clusters heats up CMB photons

Sunyaev & Zeldovich (1970), SZ effect





El Gordo Cluster

What's in a galaxy cluster?

Galaxies



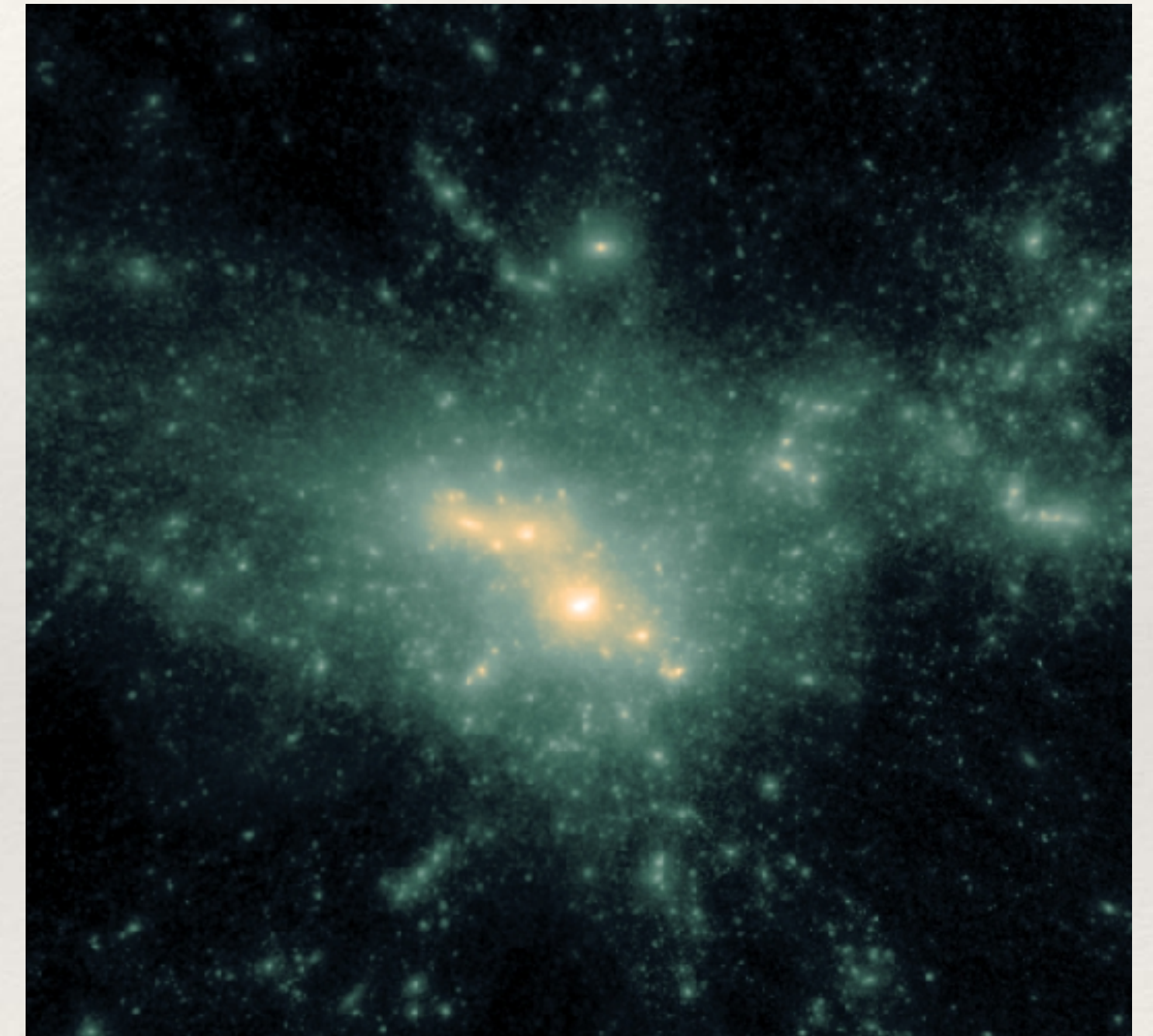
2%

Hot gas



10%

Dark matter



88%

The Universe caught speeding*

1998: Perlmutter, Schmidt, and Riess

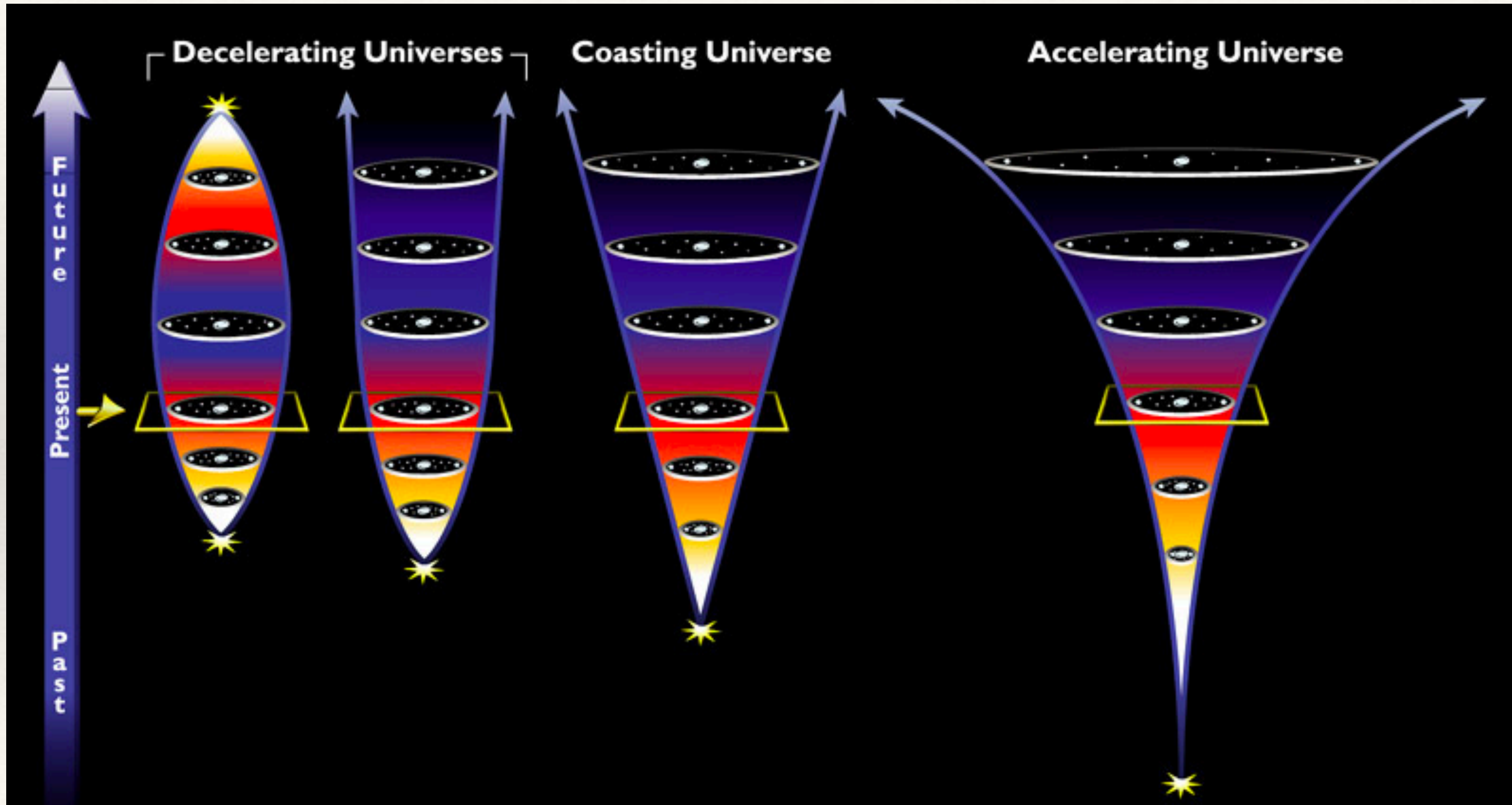


Type Ia Supernovae

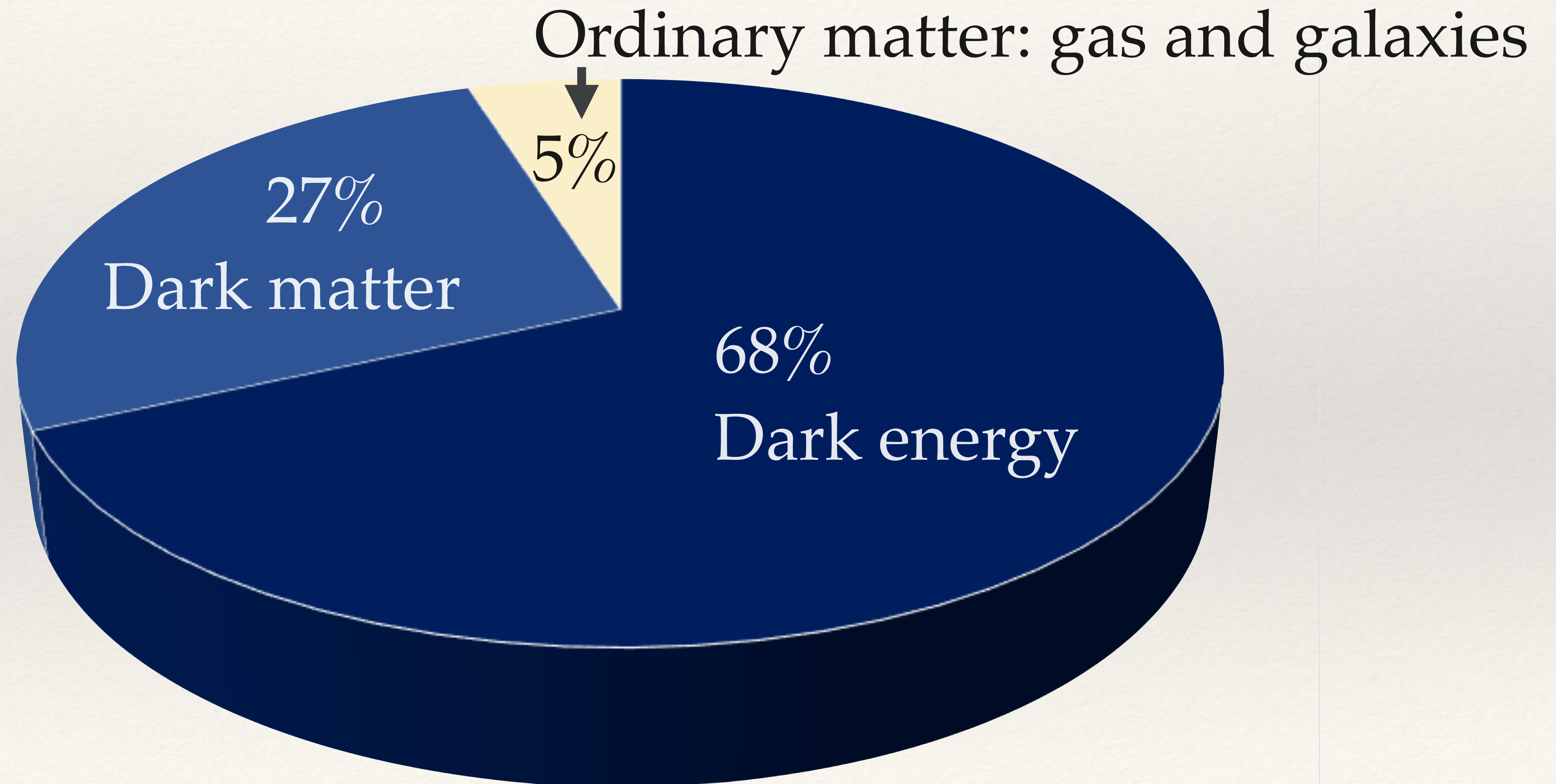


* borrowed from Dr. Dragan Huterer

The Universe caught speeding

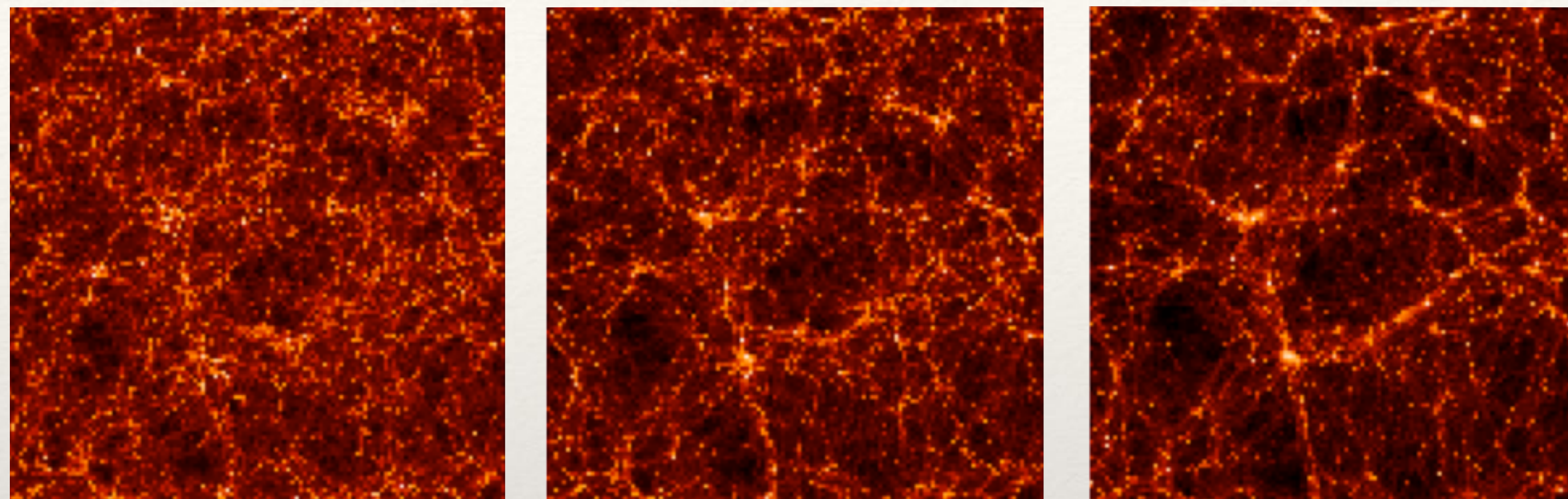


What's the Universe made of?

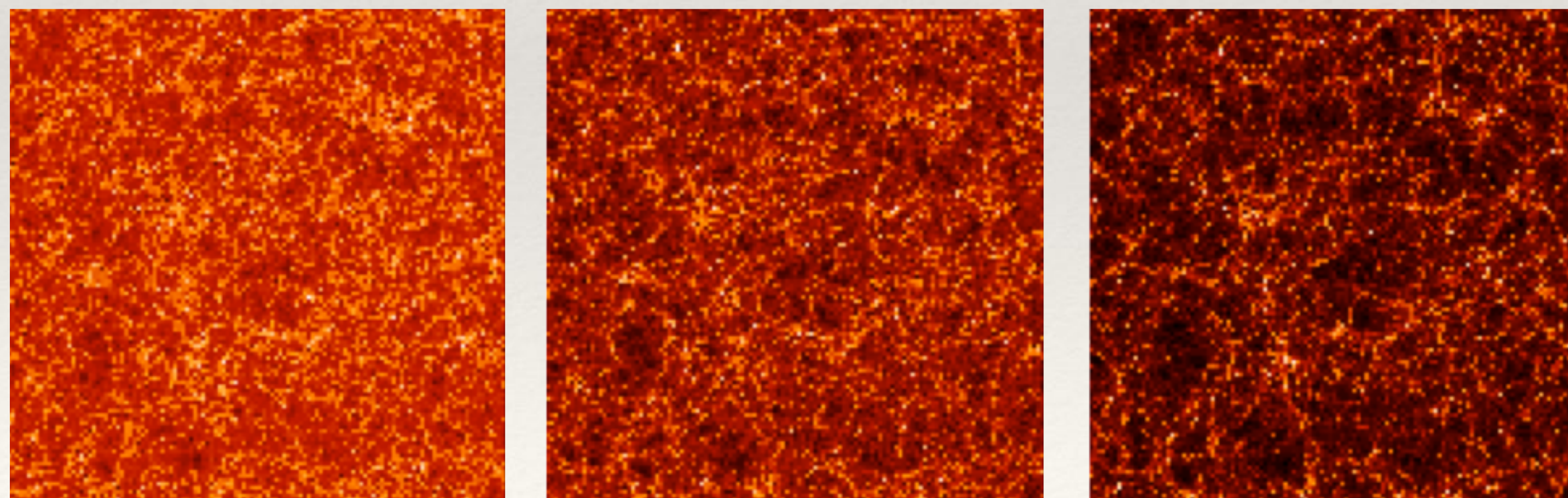


Dark energy slows down the formation of clusters

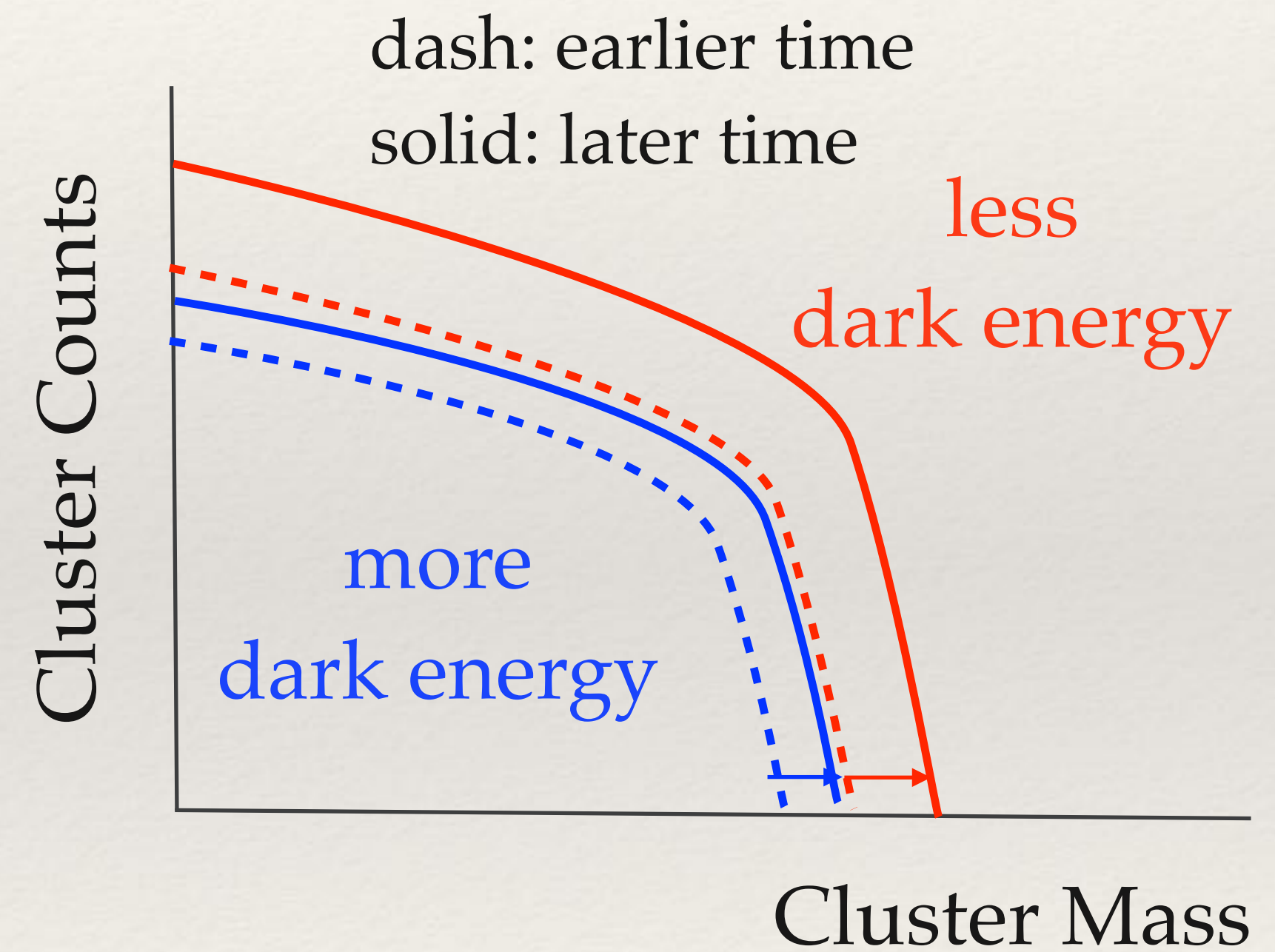
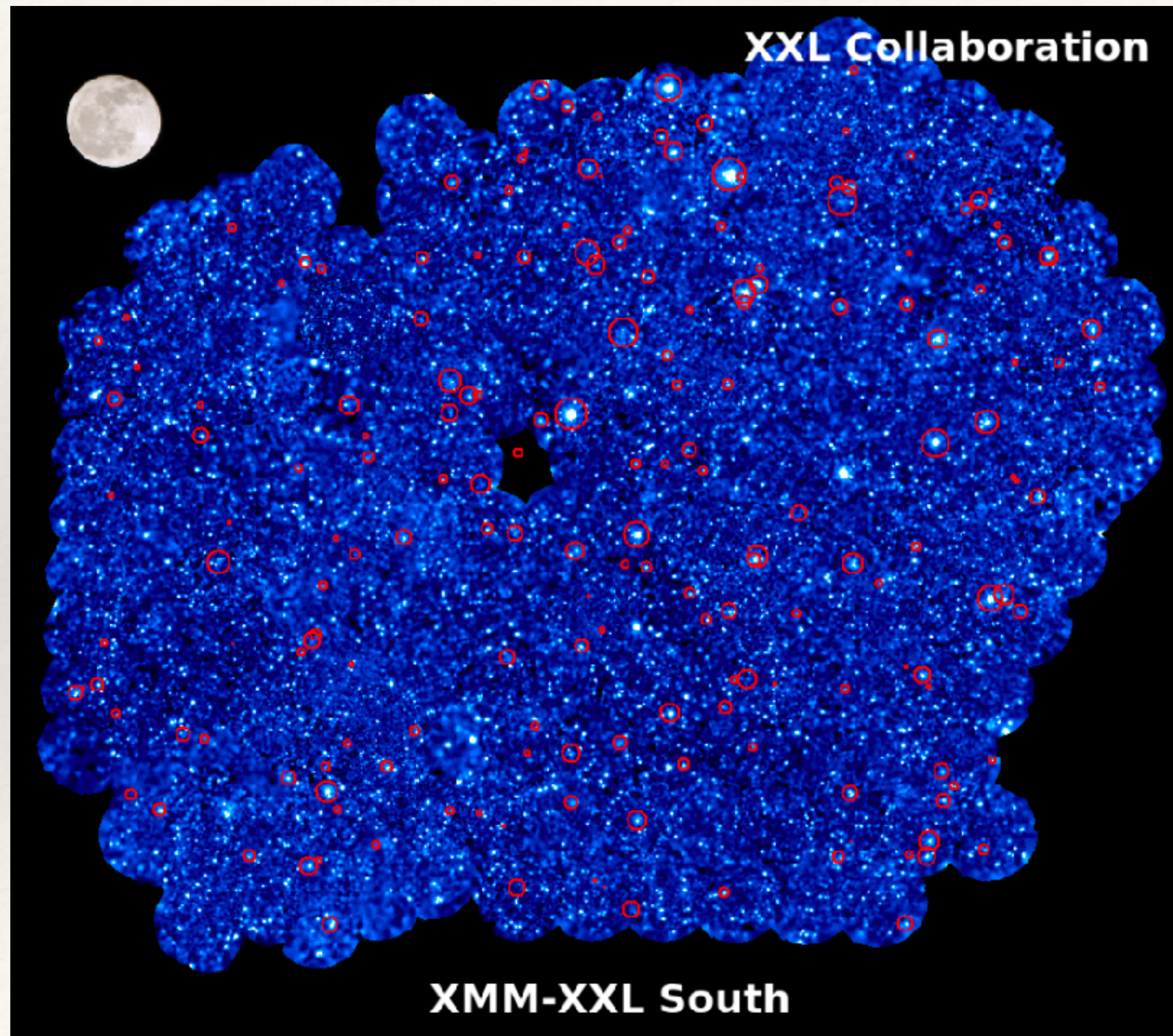
With dark energy



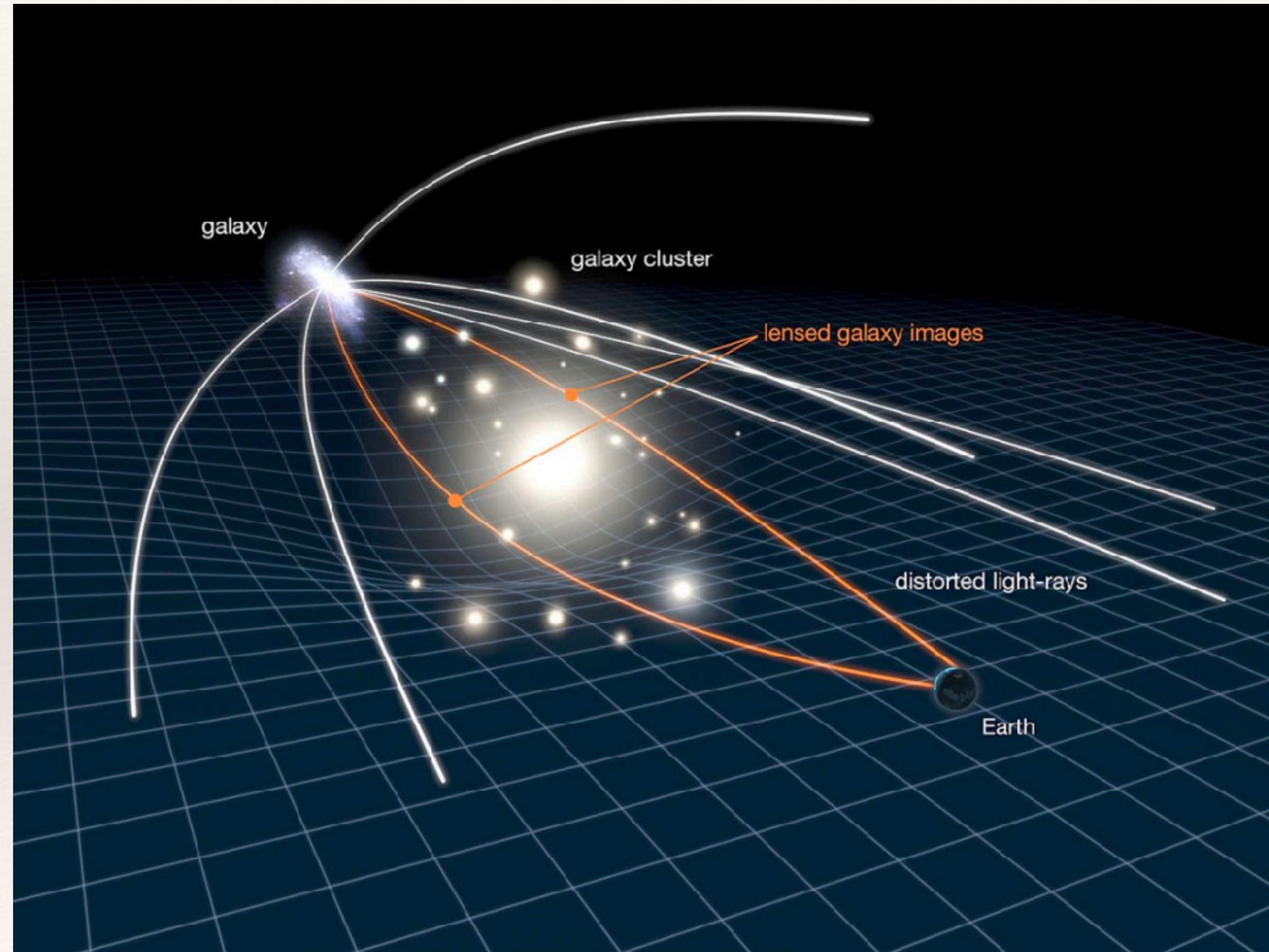
Without dark energy



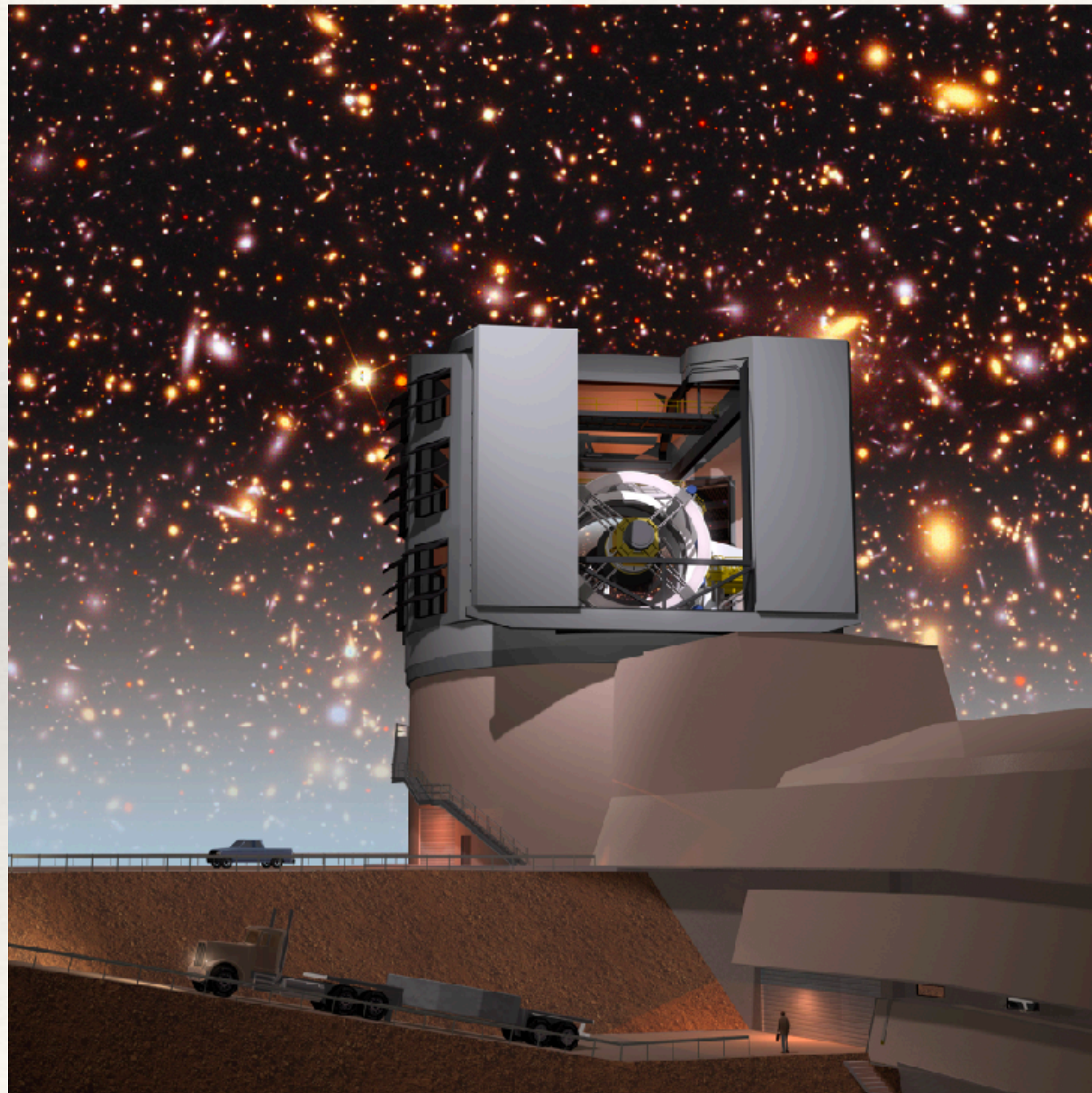
Surveys of galaxy clusters



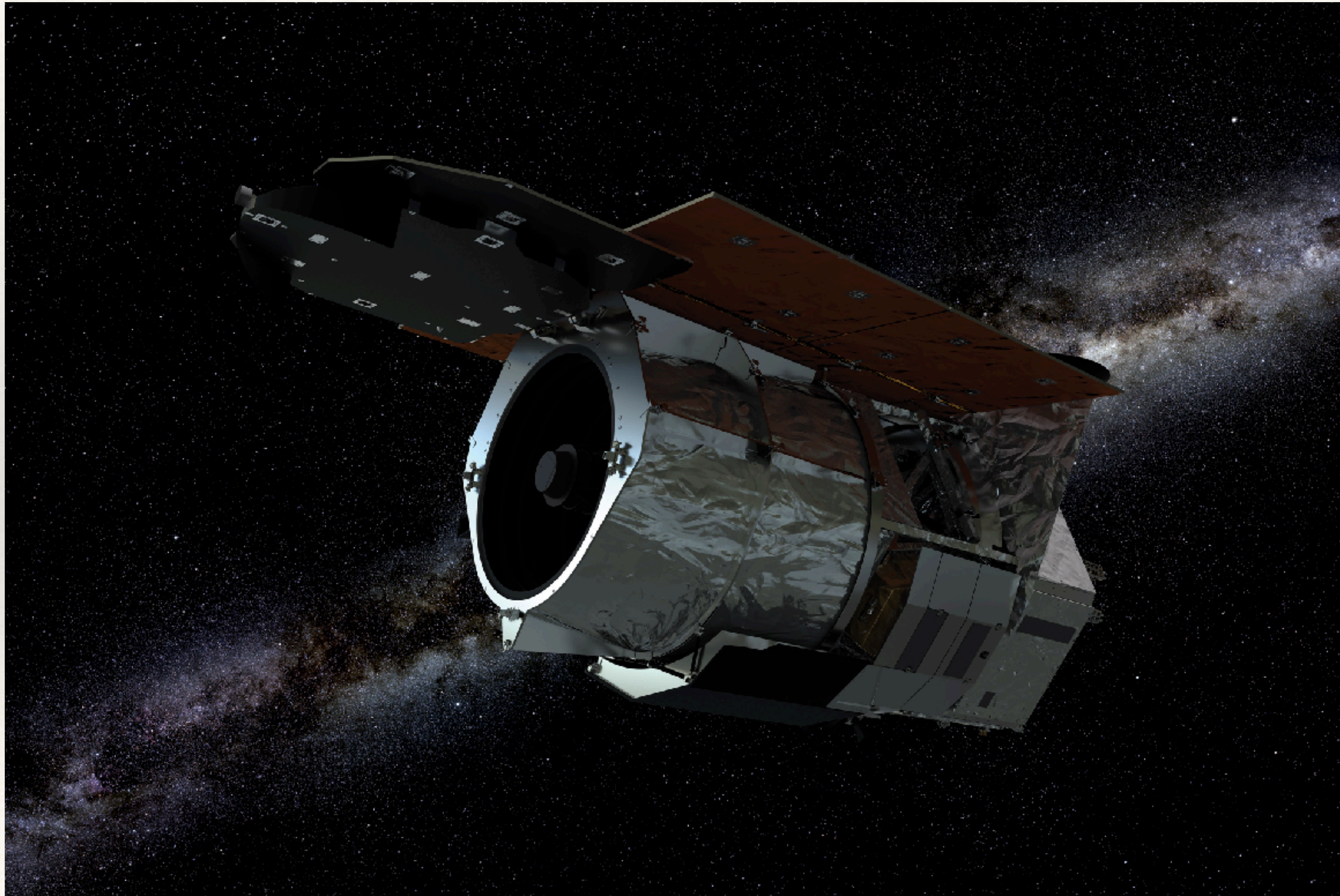
Gravitational Lensing



Vera C. Rubin Observatory



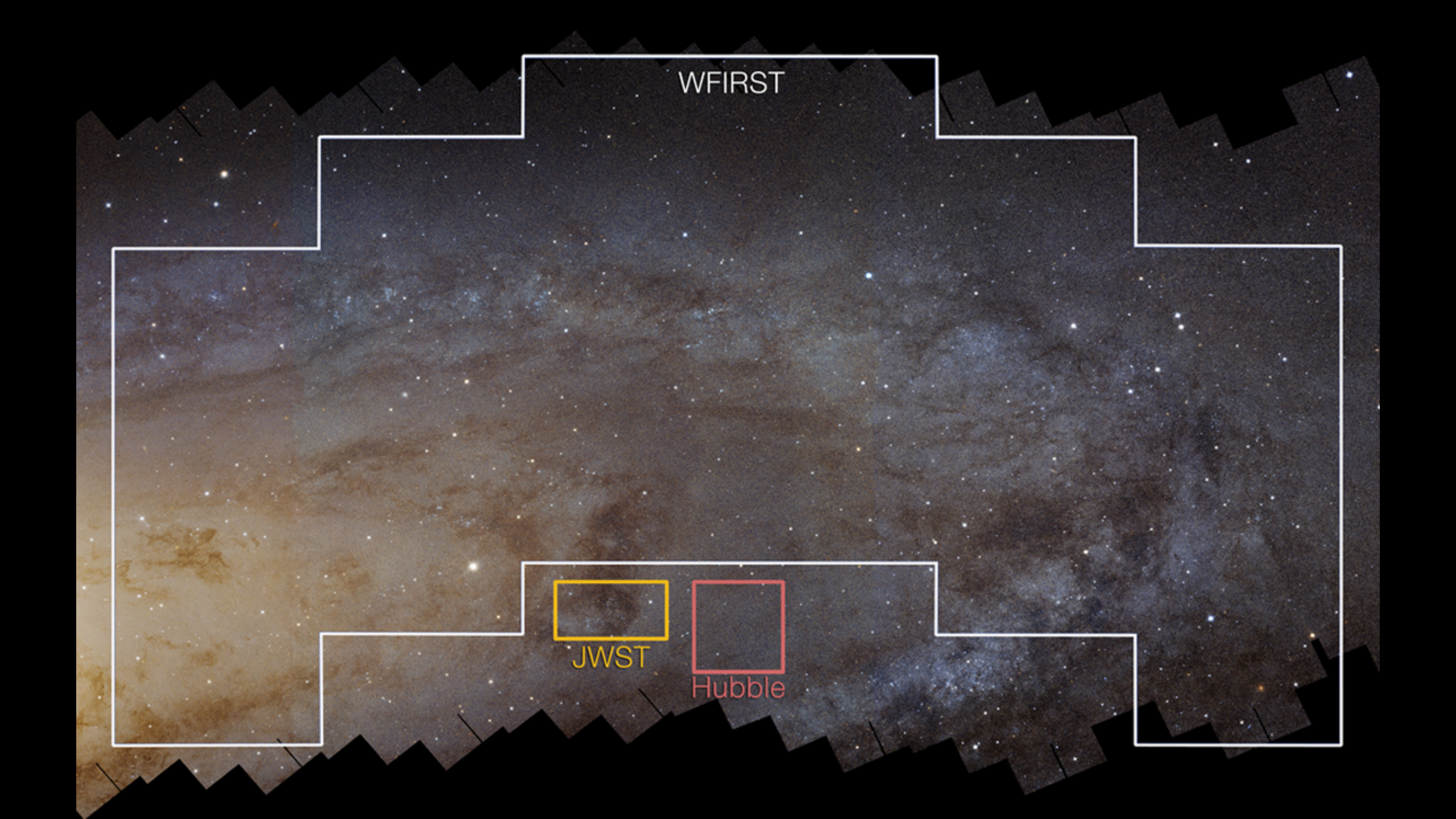
Nancy Grace Roman Space Telescope



Nancy Grace Roman (1925-2018)



- Creator of NASA's space astronomy program
- Leader of the planning of Hubble Space Telescope — “Mother of Hubble”



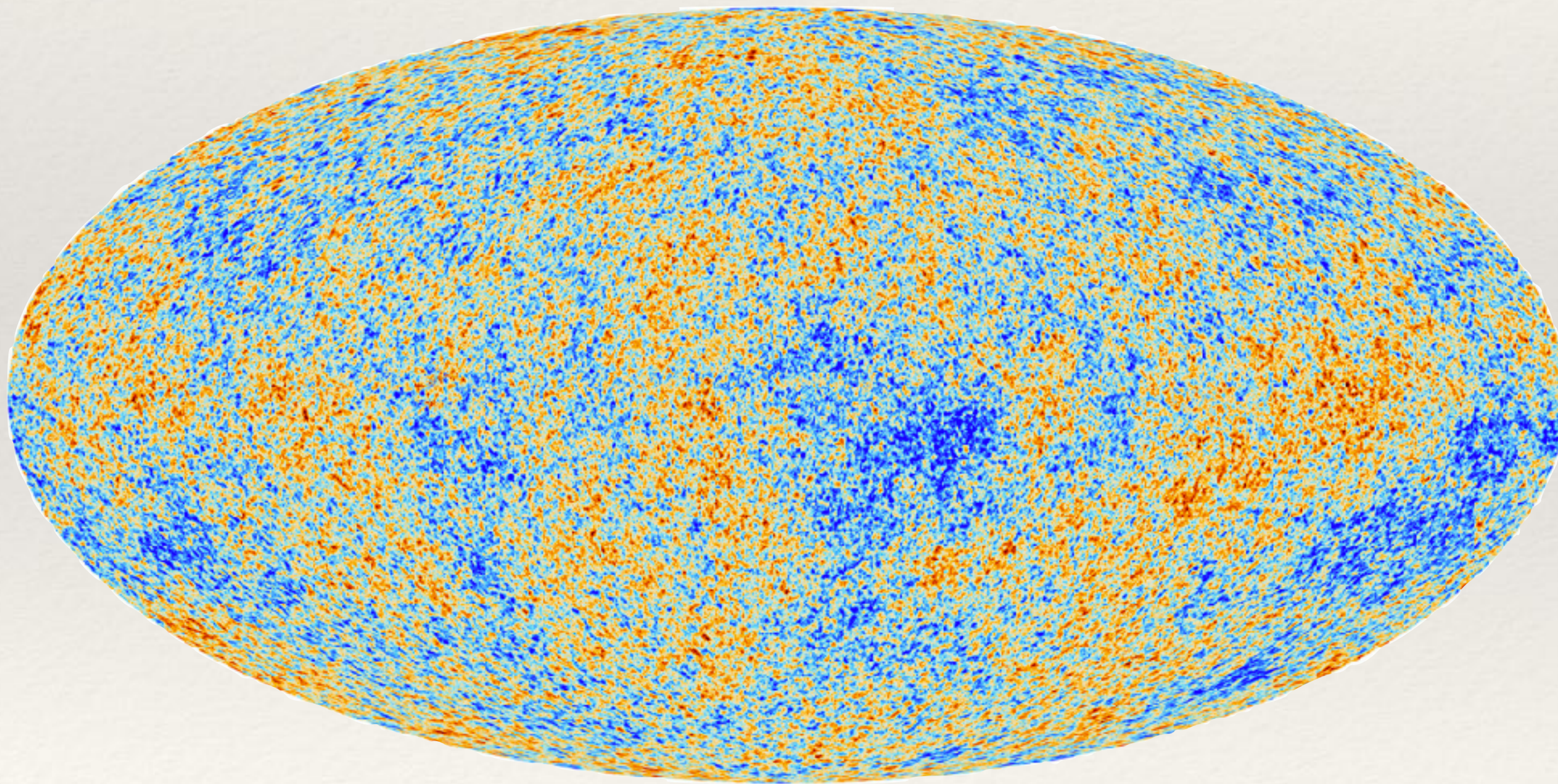
WFIRST

JWST

Hubble

The Great Debates of 2020s

1. How fast is our Universe expanding? (Hubble constant tension)



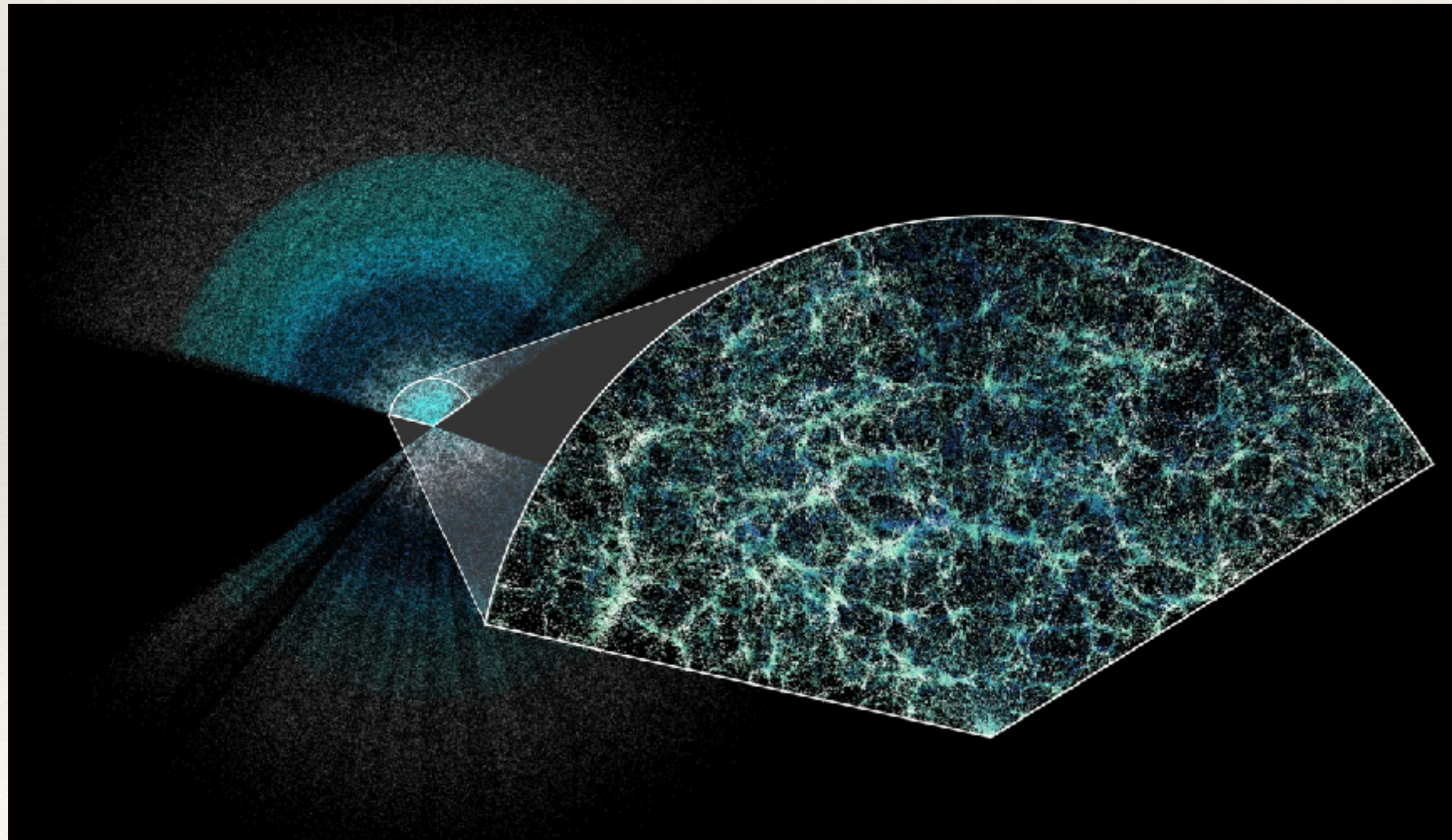
VS.



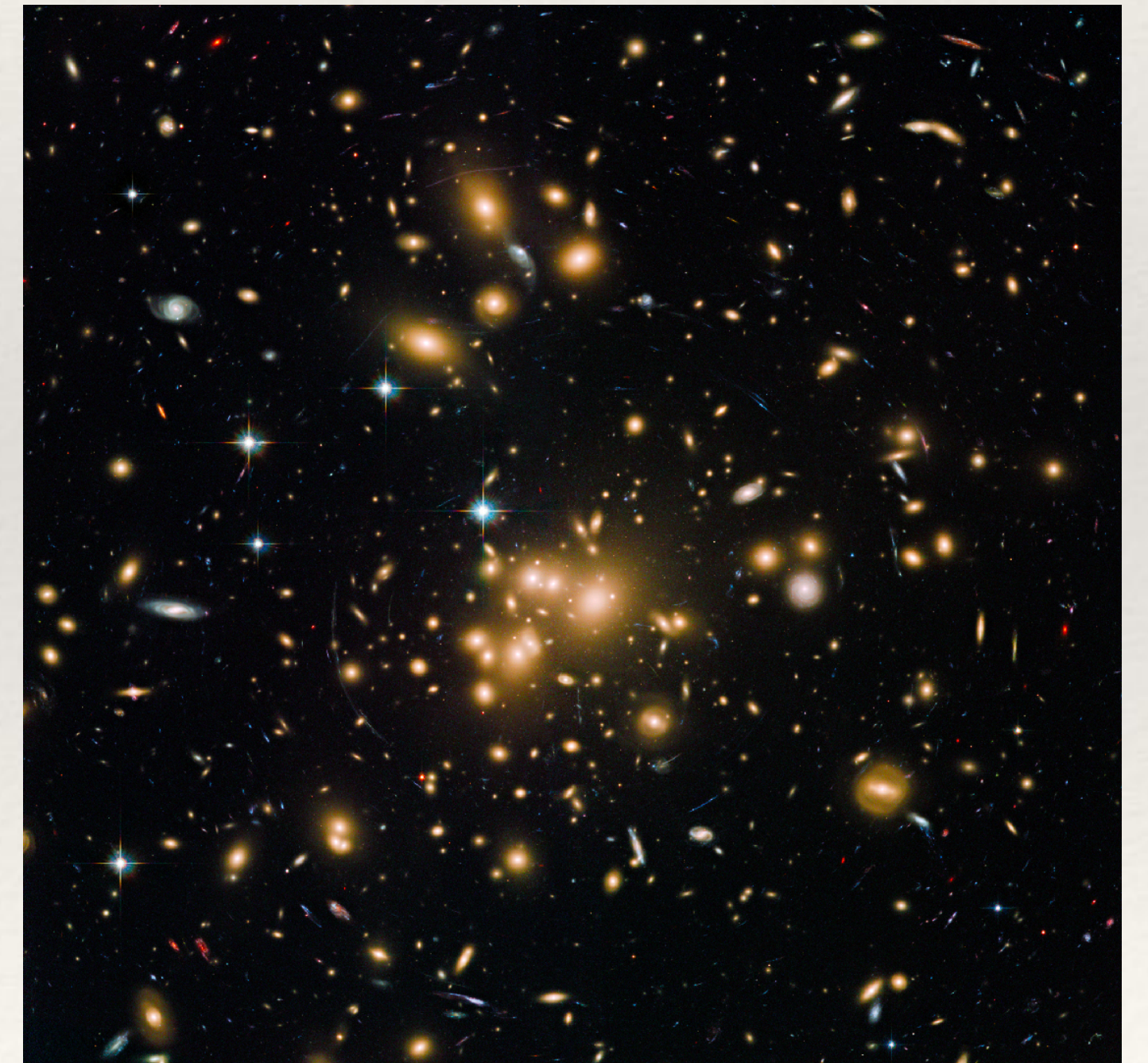
The Great Debates of 2020s

2. Is dark energy weakening with time?

Results from the Dark Energy Spectroscopic Instrument (DESI)



VS.



Summary

