Durham University

DiRAC

The cosmology talk: why are we here?

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1) What we think we know

2) Outstanding issues

What we want to know:

JWST

Sizes?

Different times?

Lensing?

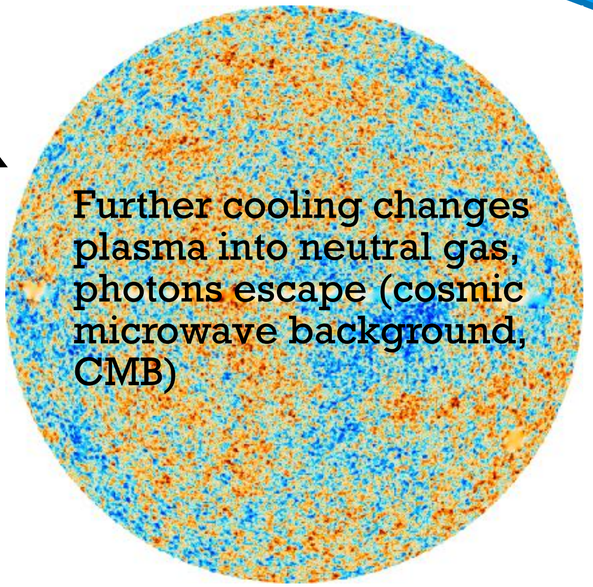
Colours?

Shapes?

Current best guess:

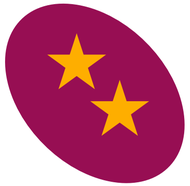
Rapid expansion of singularity 13.8 billion years ago (inflation), then expansion starts to slow

Universe rapidly cools, first dominated by radiation (hot big bang, HBB) then by matter (protons, neutrons, dark matter)



Further cooling changes plasma into neutral gas, photons escape (cosmic microwave background, CMB)

Dark matter collapses into haloes, gas also collapses then cools to form first stars ~50 million years after HBB



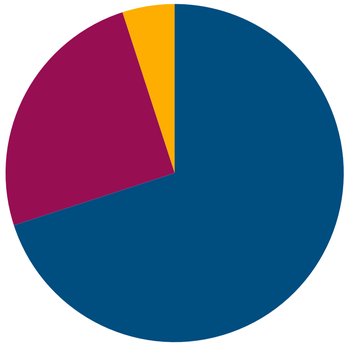
Stars reionise the neutral gas into plasma within 1 billion years after HBB

Collapse of dark matter and gas continues, building larger galaxies formation of stars peaks ~3 billion years after HBB

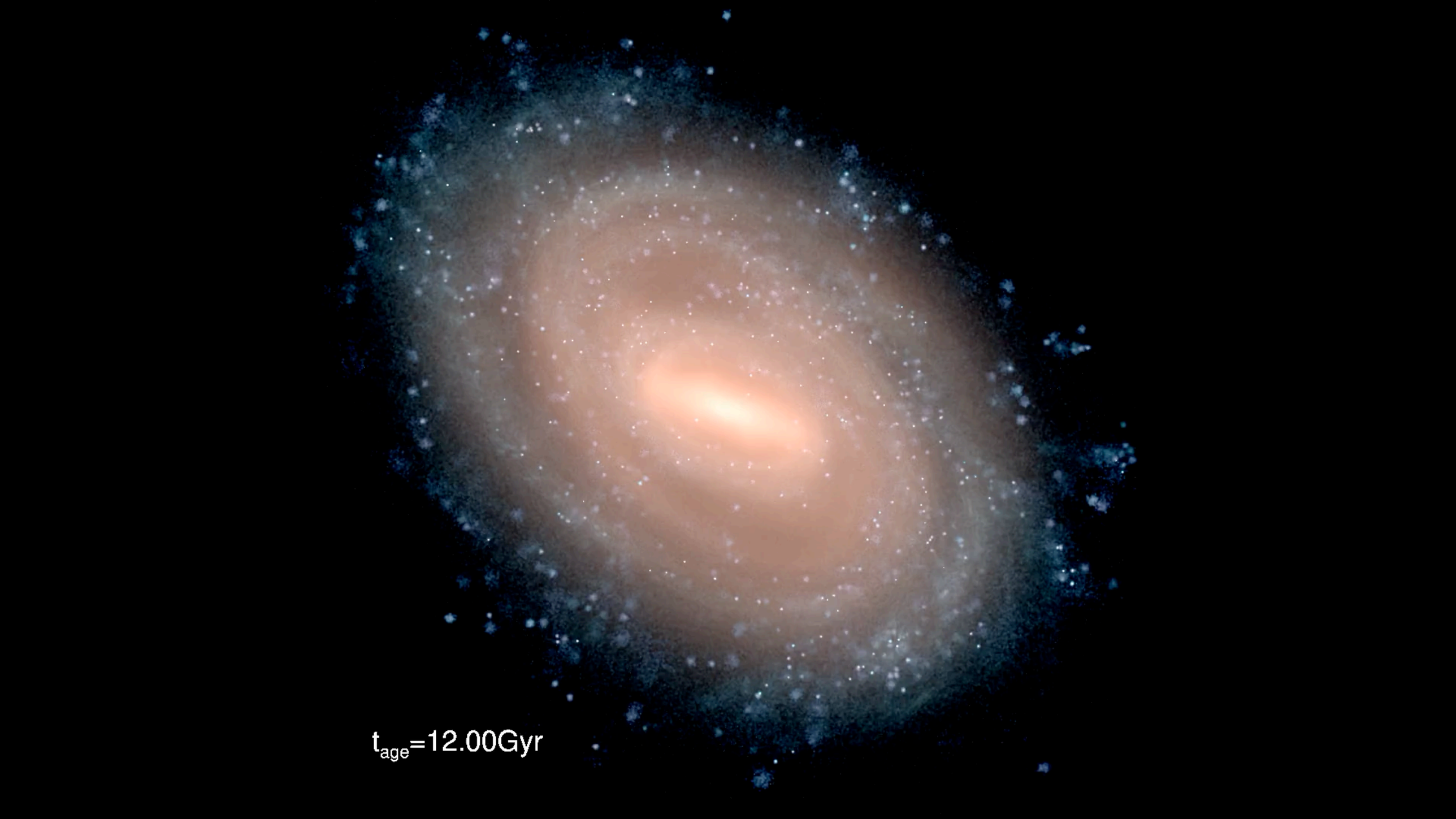
Expansion starts to speed up, appearance of dark energy

Present day universe:

70% **dark energy**,
25% **dark matter**,
5% **normal matter**



See: Crash Course Pods: The Universe (Katie Mack & John Green)


t_{age}=12.00Gyr

Outstanding issues:

1) What is dark energy?

2) What is the current expansion rate of the Universe?

3) What is dark matter?

4) How do galaxy formation processes interact to generate the observed galaxy population statistics?

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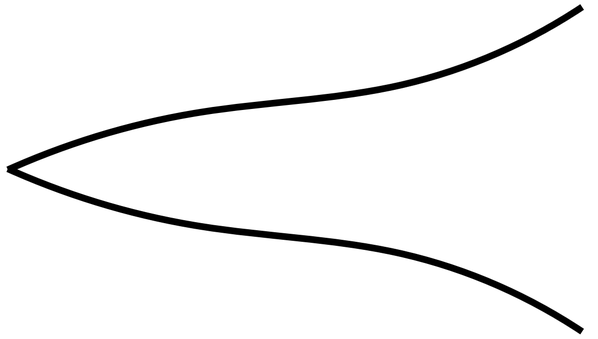
What is dark energy?

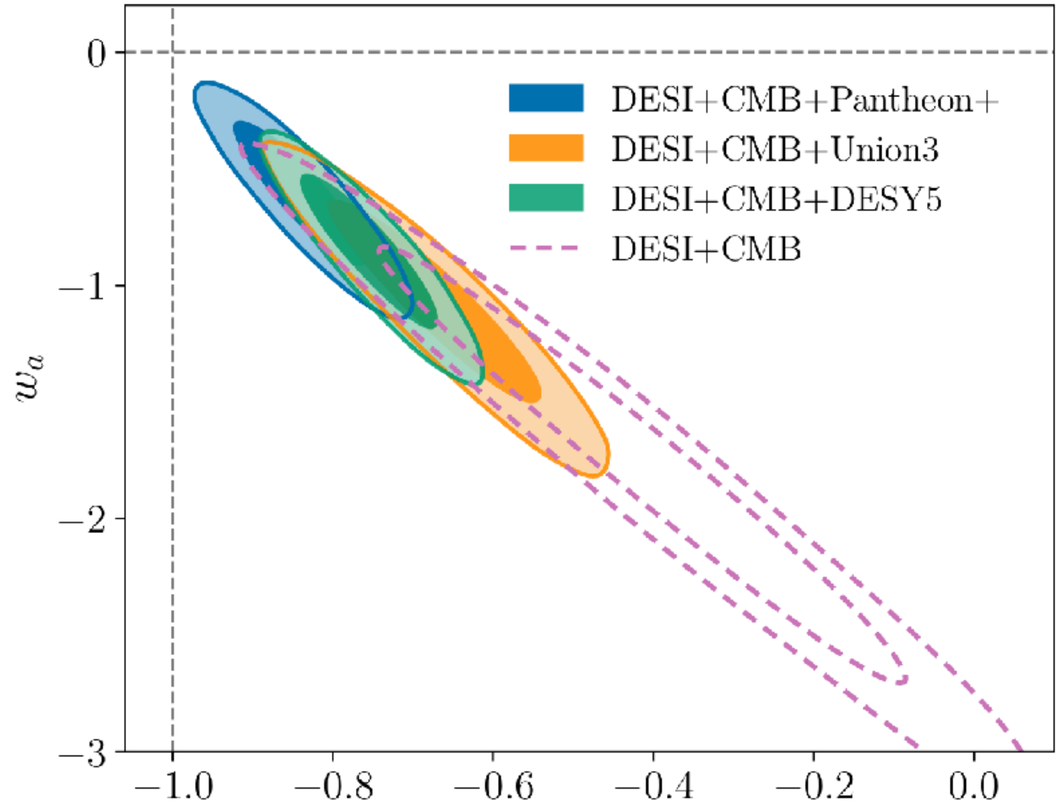
Energy source that accelerates the expansion

Simplest solution: cosmological constant, Λ, space has own energy density

Recent DESI survey results prefer something more complicated

Uncertainties in role of supernovae in the measurement





DESI Collaboration 2025

What is dark energy?

ICC contributes the FLAMINGO simulations w/ Leiden and collaborators

Perform simulations large scale simulations with the EAGLE galaxy formation model

Use cosmological constant and its alternatives

Requires very large volumes to

simulate, radius 10% of the visible Universe

Biggest run has >10080^3 resolution elements

Largest snapshot on disk: 25TB

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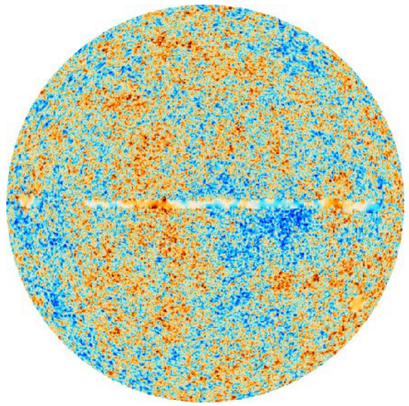
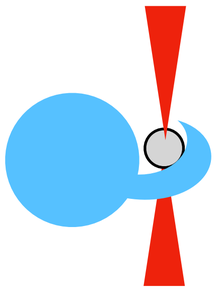
What is the current expansion rate of the Universe?



vs.



Present day expansion described by Hubble parameter, H0

Can be computed using CMB and white dwarf explosion supernovae (Type 1A)

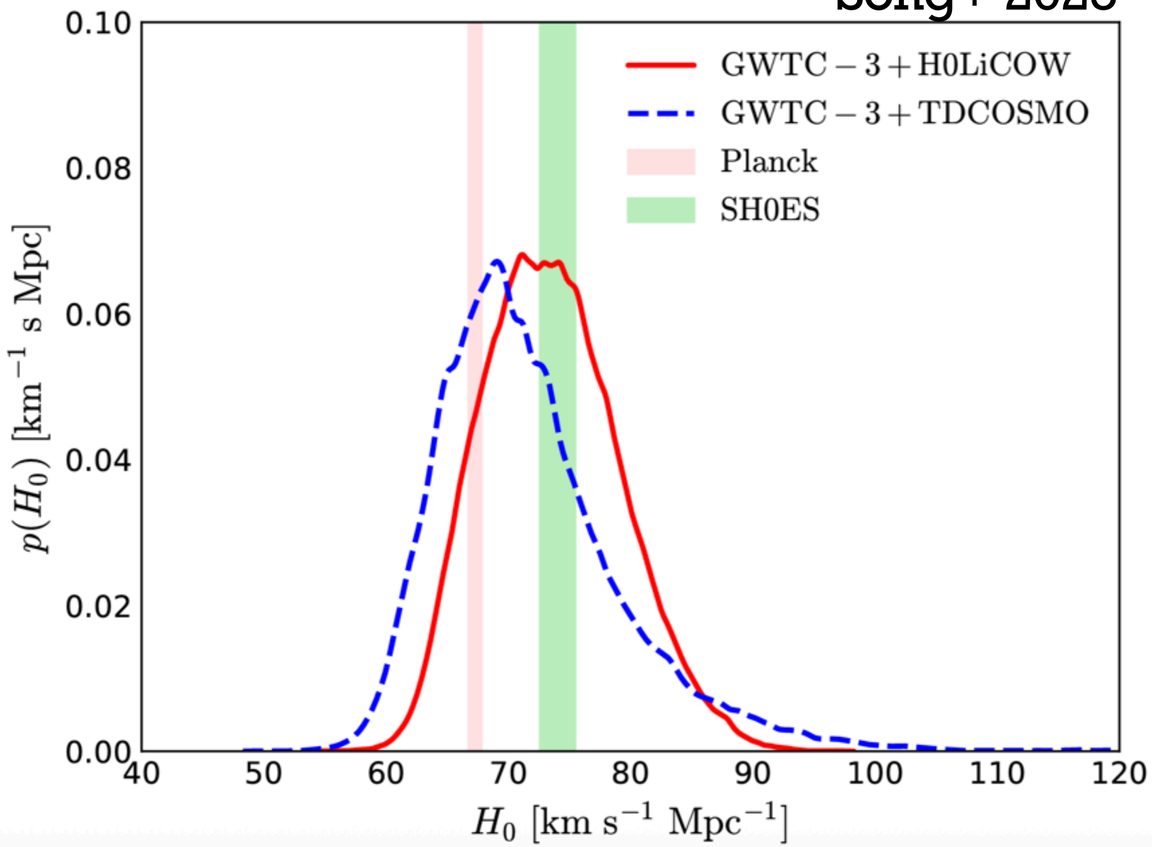
Give different answers outside margin of error

Potential for gravitational waves, much larger uncertainties at present

Solutions include undiagnosed systematic errors, local void, differences in the cosmological model

May also be answered by FLAMINGO- style simulations

Song+ 2025



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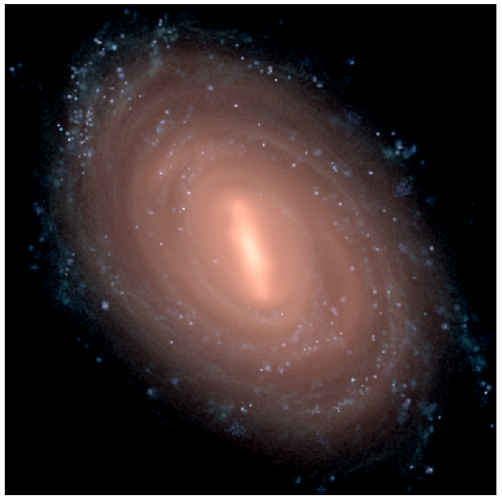
What is dark matter?

Observations of galaxy rotation curves, gravitational lensing and the CMB indicate the total matter density of the Universe is 5x more than the proton/neutron content

No effective interaction with light / electromagnetism => dark matter ('transparent matter' more appropriate)

Collapses to clouds (haloes) in which gas condenses to form stars



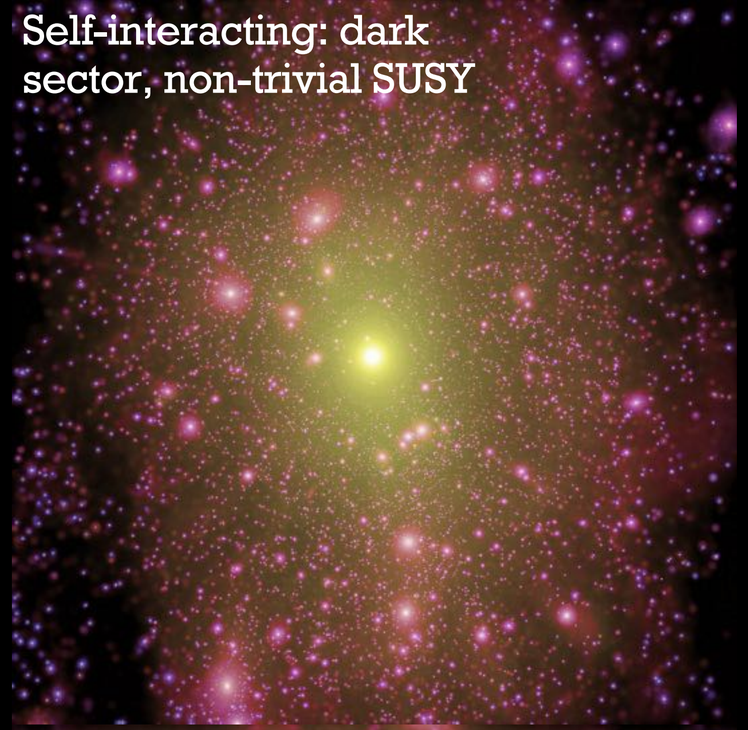
What is dark matter?

Different particles lead to different predictions for halo/galaxy properties

Include: halo shape, number of Milky Way satellite galaxies, satellite densities, halo shapes, gravitational lensing signals

ICC involvement through lensing studies, LYRA, COLIBRE, Auriga Superstars galaxy formation models, Euclid, modelling X-ray decay signatures

Cold: WIMP, QCD axion, primordial black hole



Self-interacting: dark sector, non-trivial SUSY

Warm: sterile neutrino, gravitino

Fuzzy: axion-like particle

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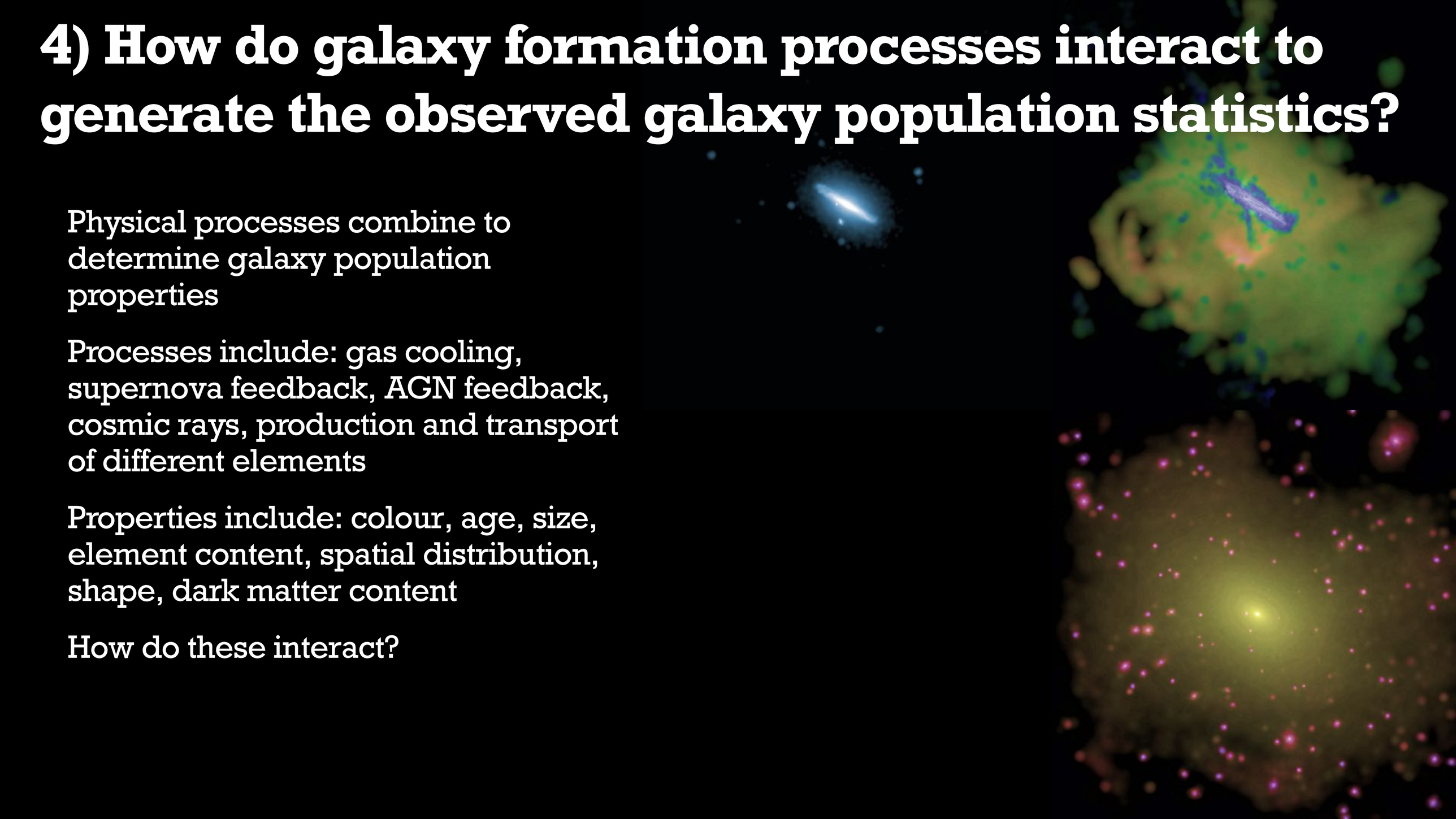
Physical processes combine to determine galaxy population properties

Processes include: gas cooling, supernova feedback, AGN feedback, cosmic rays, production and transport of different elements

Properties include: colour, age, size, element content, spatial distribution, shape, dark matter content

How do these interact?



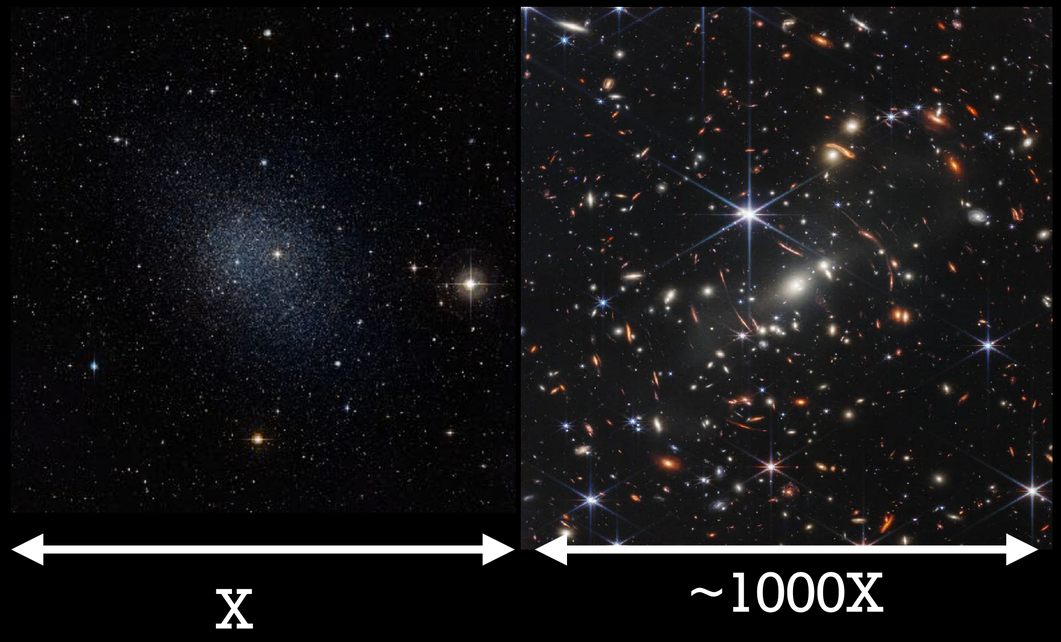
4) How do galaxy formation processes interact to generate the observed galaxy population statistics?

Smallest galaxies, ~1kpc across, largest clusters ~2Mpc, 1000 orders of magnitude => lots of resolution elements to track processes

Large spatial volume to sample the galaxy population comprehensively => even more resolution elements

Large memory requirements required for compute

Durham efforts include FLAMINGO, COLIBRE, LYRA, Auriga Superstars, SKA, LSST, AGN & stellar feedback researchers



One more thing: VR headset work

Cosmological simulations give location of galaxies in 3D space, very useful for VR headsets

Making a 3-minute movie on the formation of a Milky Way-like galaxy

Run in a Meta Quest 3 headset (Whirligig 3rd party media player)

Aimed at outreach events

End, still to be done:

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