

Connecting observations of galaxies with simulations

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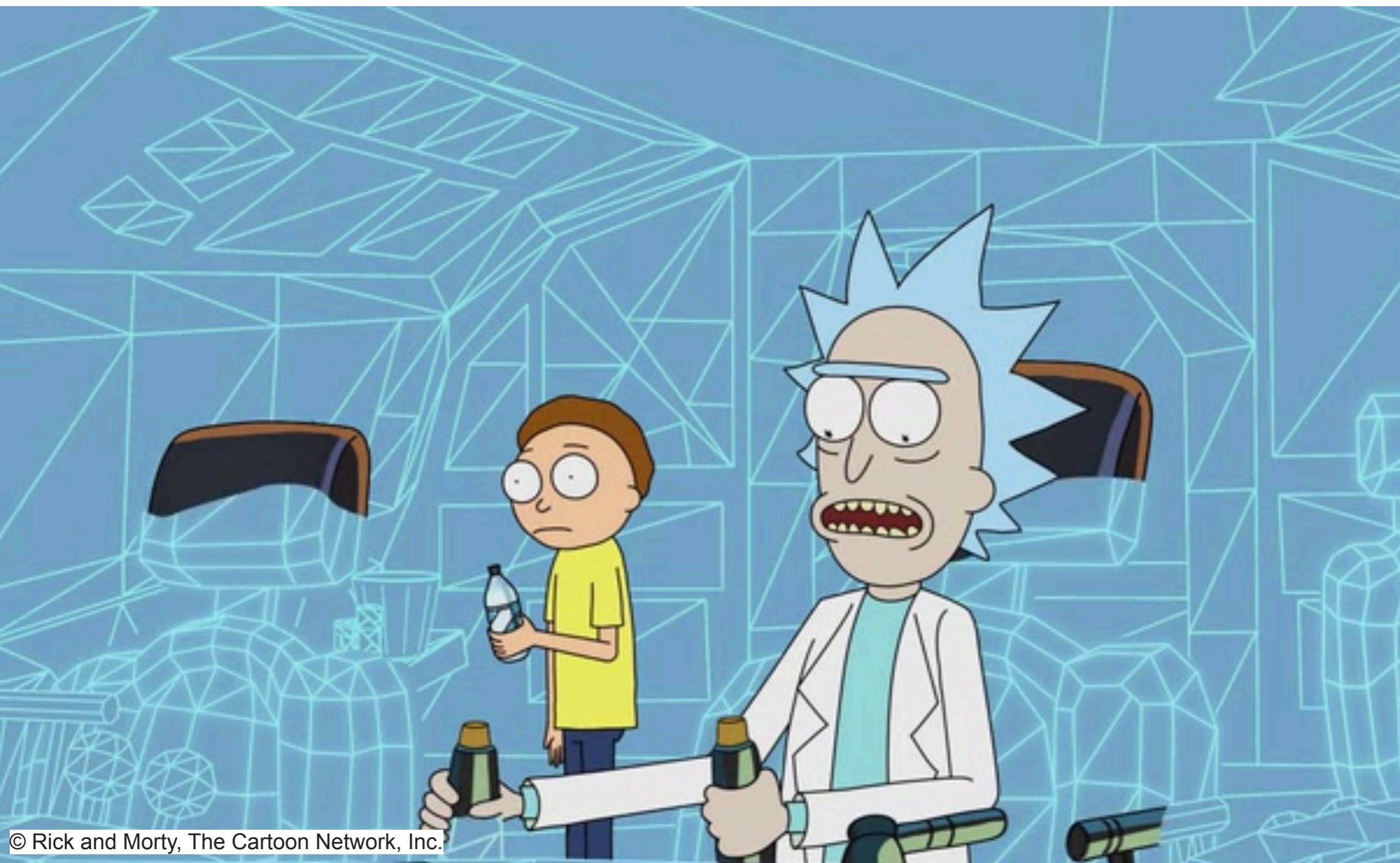


As an astronomer, this is
not what I wake up to...



Very Large Array, New Mexico

This is more likely how you will encounter me:



How did we get **here**?



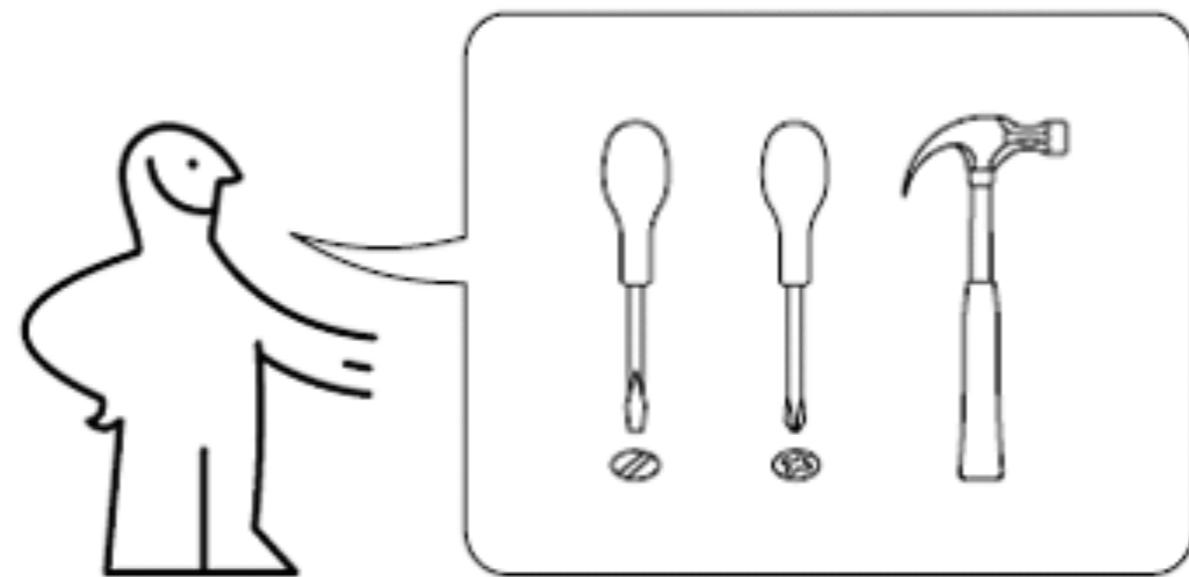
Milky Way

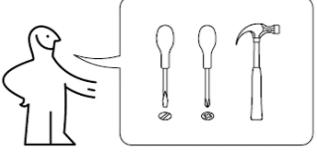
How did we get **here**?

Two problems:

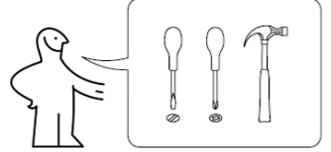
- 1) We can't see the **Milky Way** from the outside
- 2) We can't go back in **time**

What is a galaxy?





What is a galaxy?

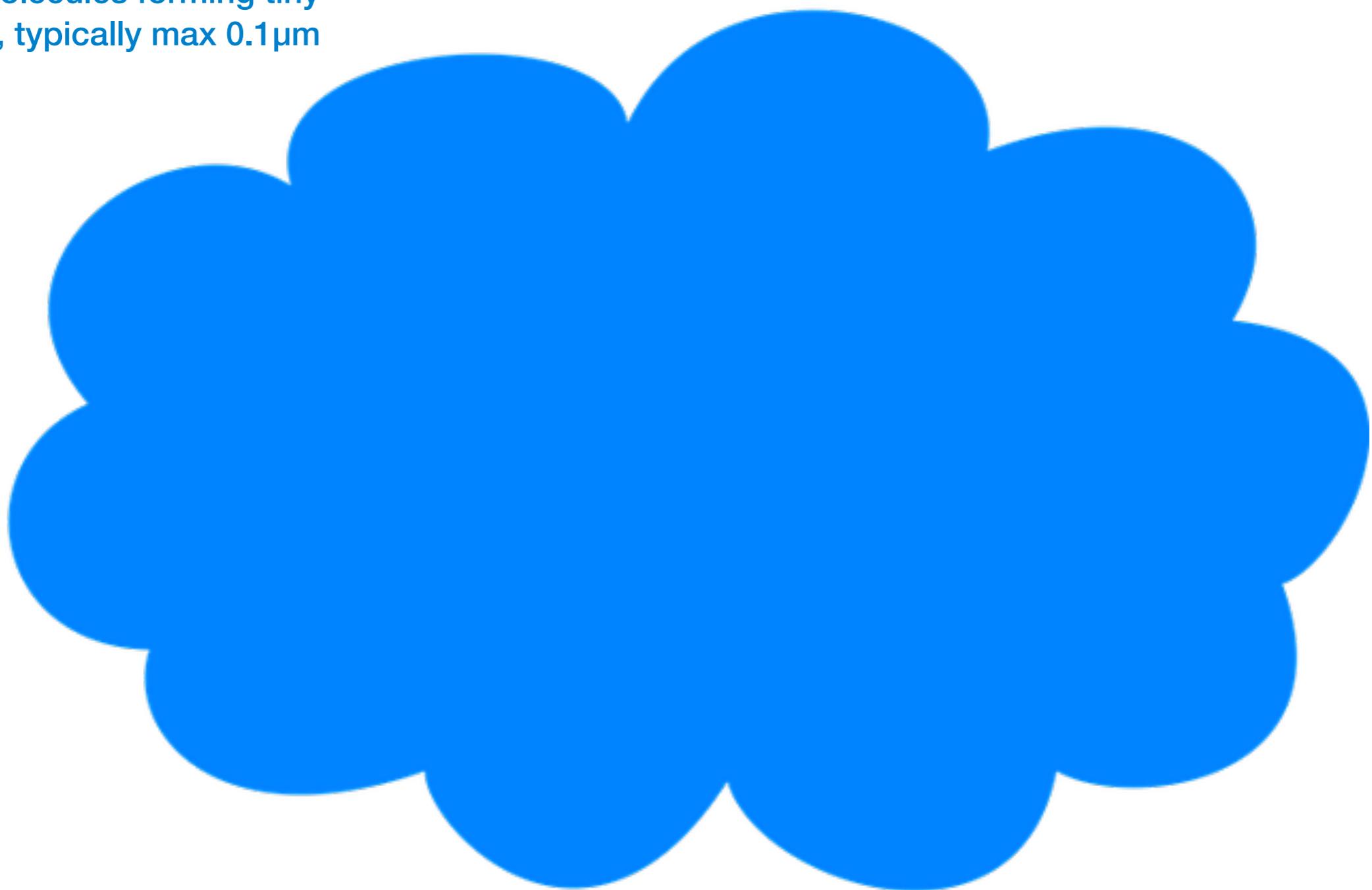


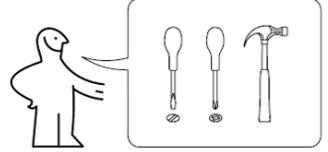
What is a galaxy?

Interstellar Medium (ISM)

GAS: mostly H and He (in the sun:
only 1.34% mass in other elements)

DUST: molecules forming tiny
particles, typically max $0.1\mu\text{m}$



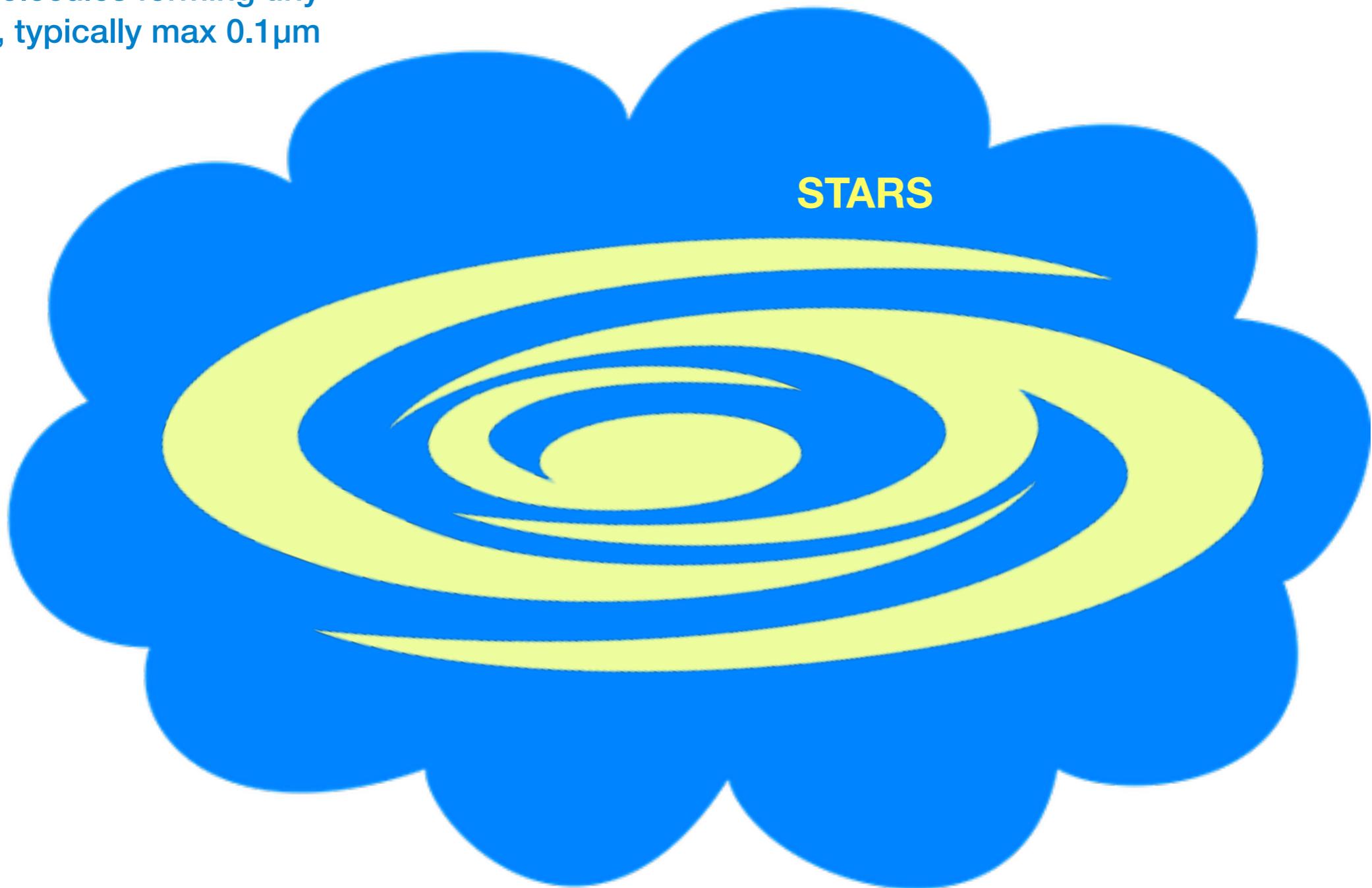


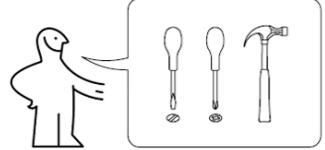
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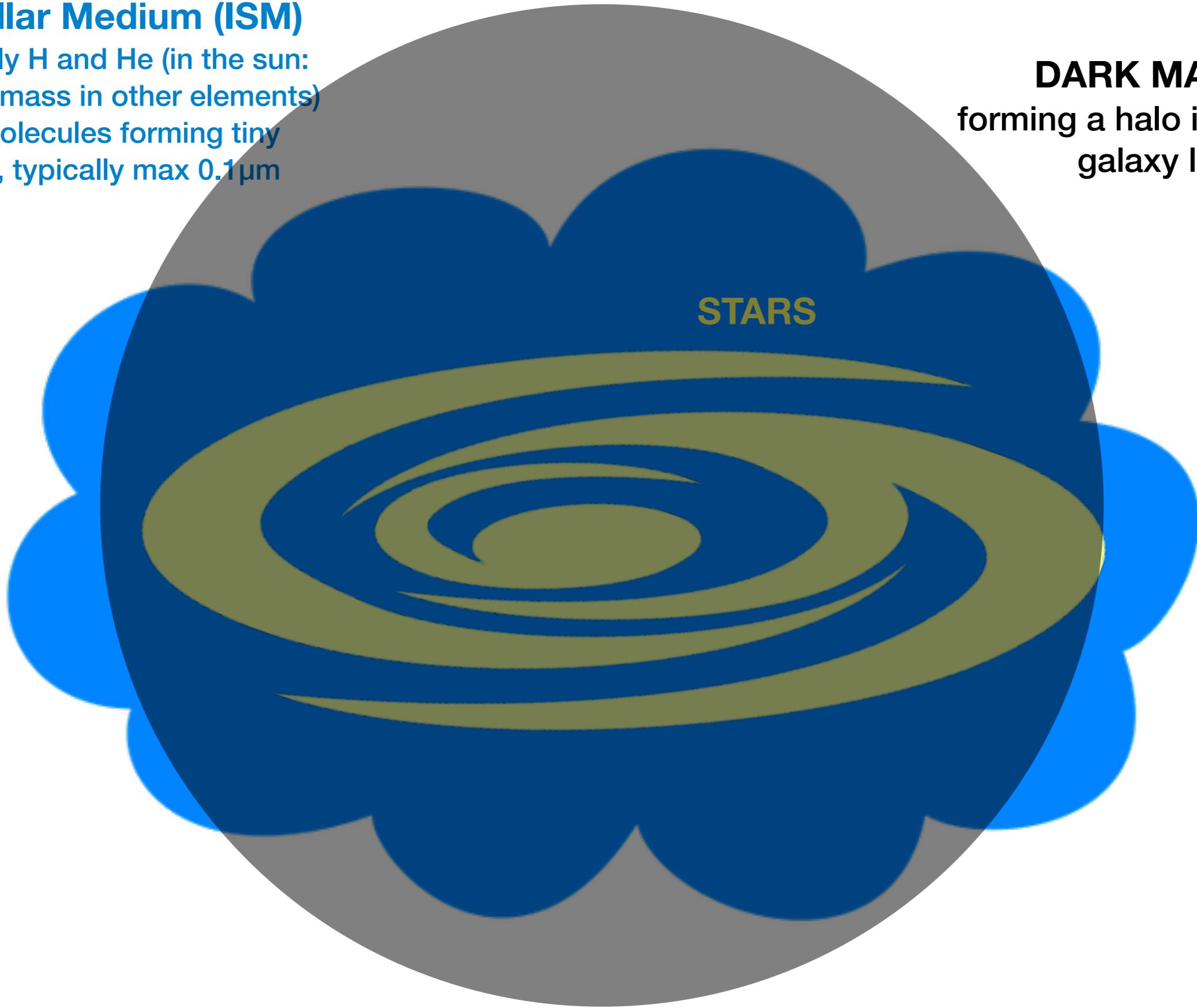


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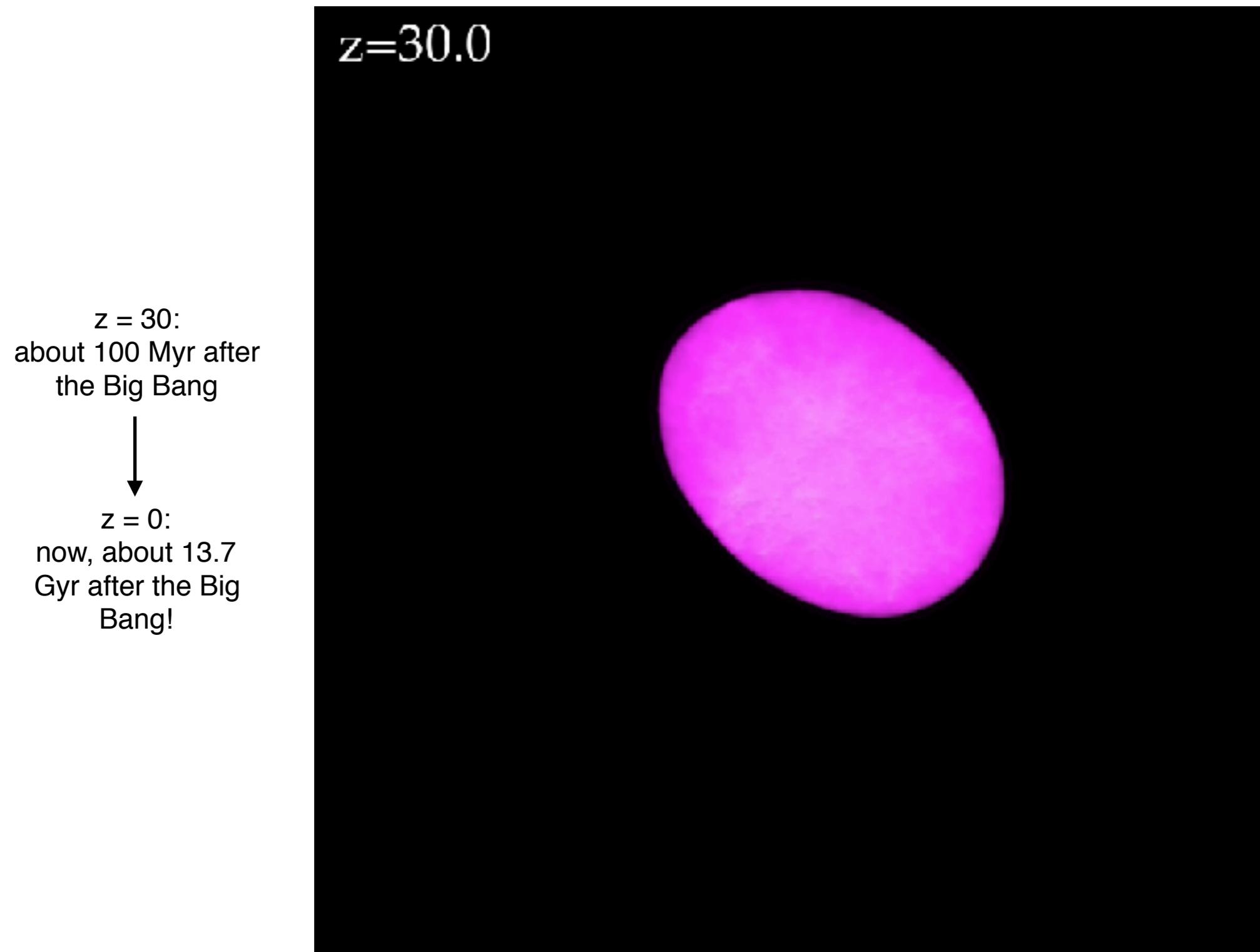
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DARK MATTER

forming a halo in which the
galaxy lives

Simulating galaxy evolution



How did we get here?

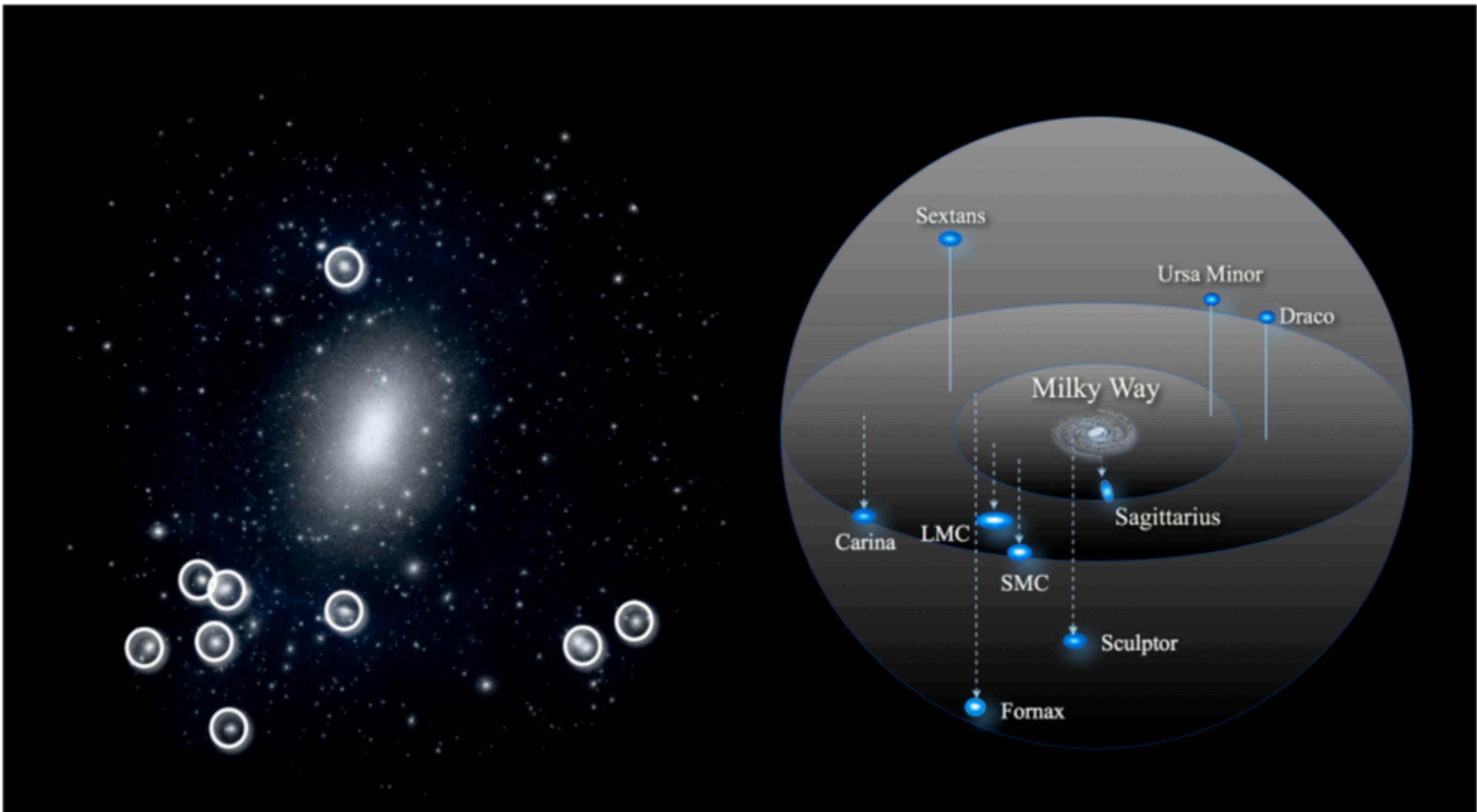
Two problems:

- 1) We can't see the Milky Way from the outside
- 2) We can't go back in time

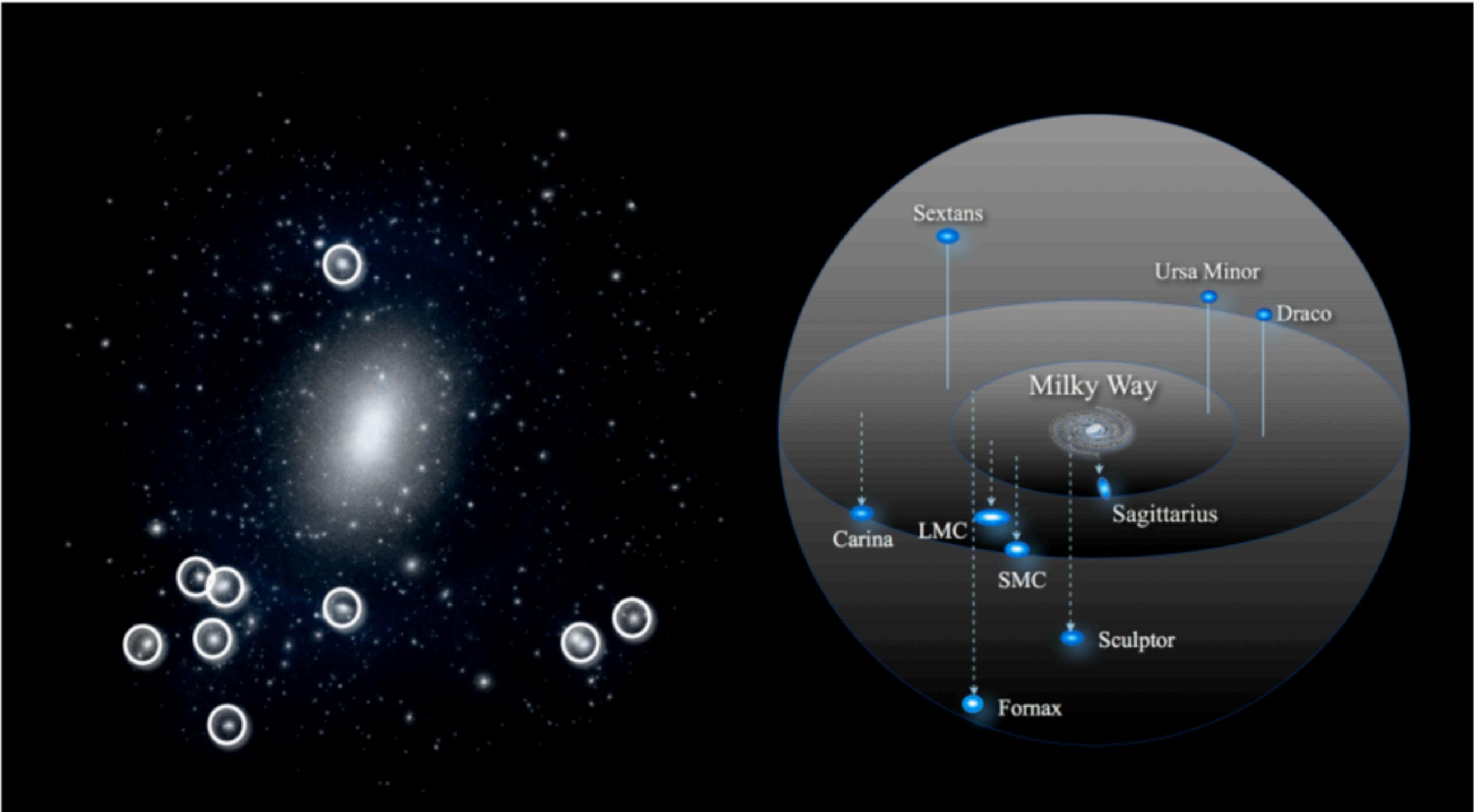
1) Simulating the Milky Way
to see it from **the outside!**

Missing Satellite Problem

Missing Satellite Problem



Missing Satellite Problem



Subhalos around a Milky Way type galaxy simulation that could all contain dwarf galaxies.

Observed satellite galaxies around the Milky Way.

Missing Satellite Problem

- solved? [Kim+17]

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- 1) Detection efficiency of sky surveys not as good as we thought.

The original survey (SDSS) was taken in New Mexico in 1998-2009, will soon be upgraded with the LSST: Large Synoptic Survey Telescope in Chile!

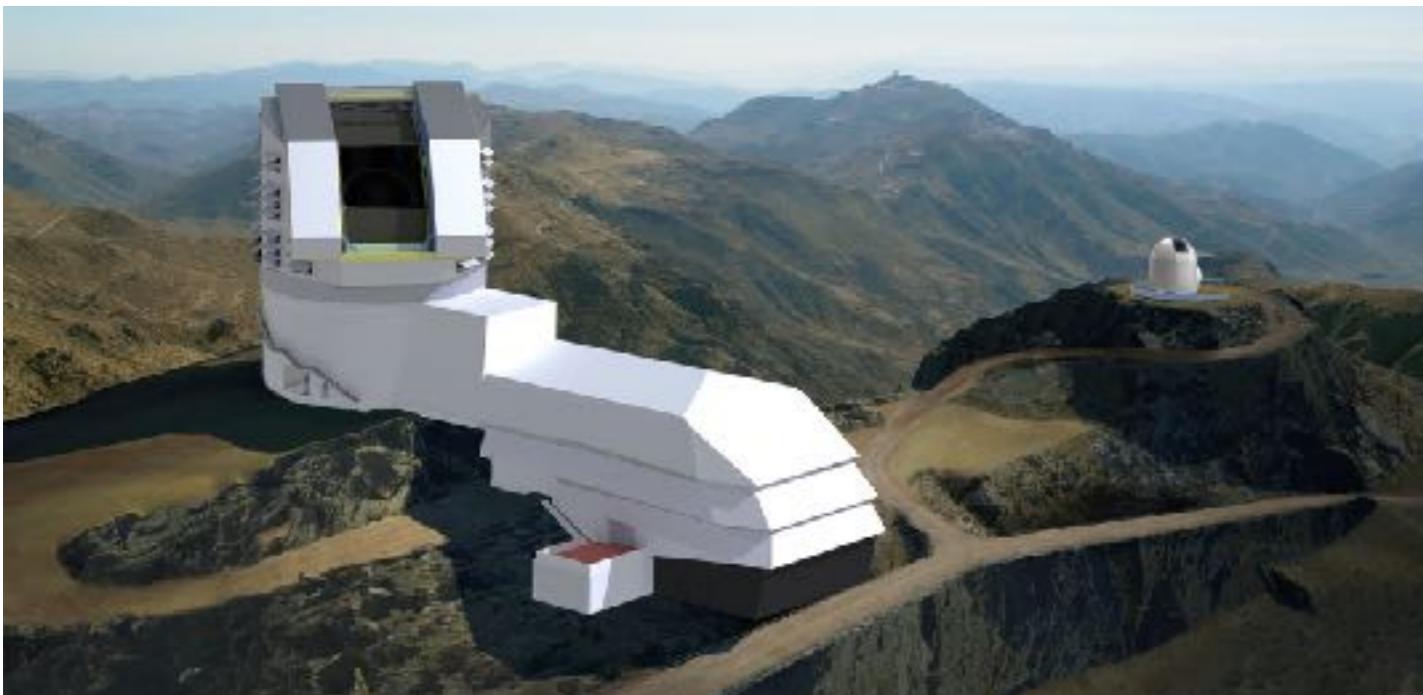


Missing Satellite Problem

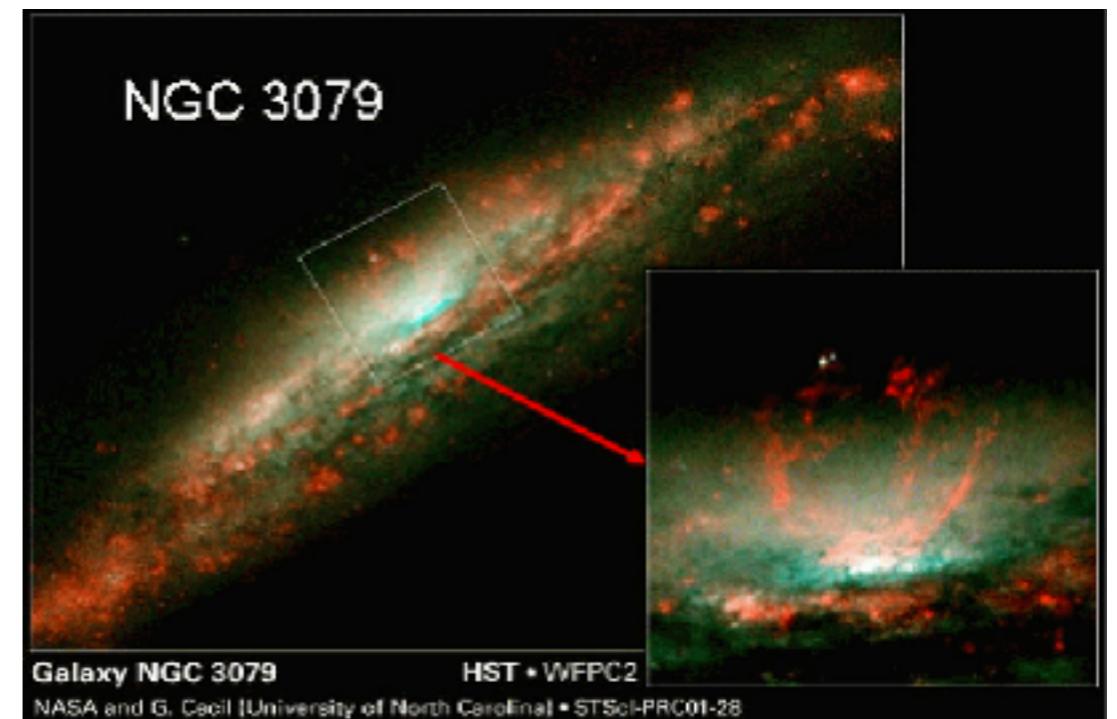
- solved? [Kim+17]

- 1) Detection efficiency of sky surveys not as good as we thought.
- 2) Star formation not as efficient as we thought in dwarf galaxies.

The original survey (SDSS) was taken in New Mexico in 1998-2009, will soon be upgraded with the LSST: Large Synoptic Survey Telescope in Chile!



Observations revealing outflow triggered by supernovae explosions, inhibiting further star formation (HST, NASA).



Summary

Two ways that simulations can go beyond observations:

1) Seeing ourselves from the outside

- by running many simulations, we can construct a Milky Way type galaxy and study it better in relation to other galaxies.

2) Going back in time

- once a simulation has been tested in the local Universe, we can take it back in time.

Some links to get more information:

FIRE project:

<https://fire.northwestern.edu/>

My research:

<http://kpolsen.github.io/sigame/>

Going forward in time...

NOW:



Andromeda
Galaxy
(M31)

Milky Way
Galaxy

Going forward in time...

In 3.75 billion years:



The Andromeda galaxy close to collision with the Milky Way

NASA, ESA, Z. Levay and R. van der Marel (STScI), T. Hallas, and A. Mellinger

Going forward in time...

In 3.9 billion years:



The Andromeda galaxy merging with the Milky Way

NASA, ESA, Z. Levay and R. van der Marel (STScI), T. Hallas, and A. Mellinger

Going forward in time...

In 7 billion years:

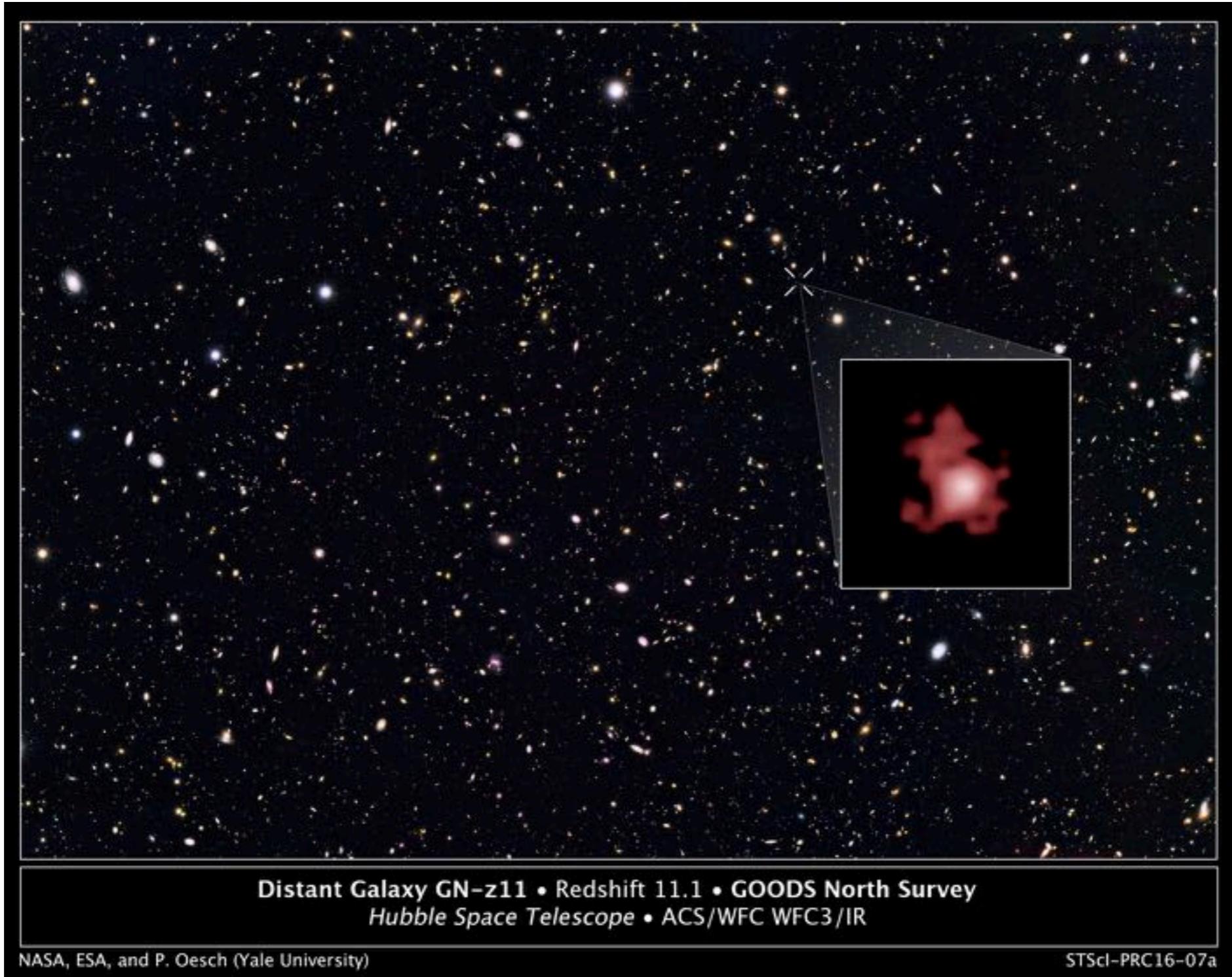


Andromeda and Milky Way forming a huge elliptical galaxy

NASA, ESA, Z. Levay and R. van der Marel (STScI), T. Hallas, and A. Mellinger

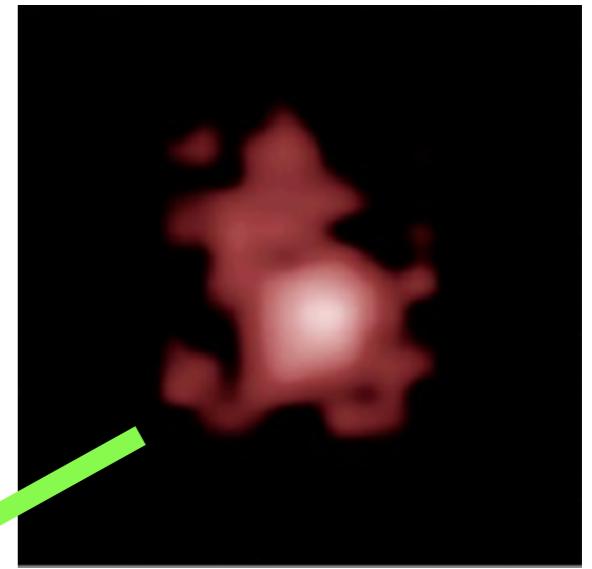
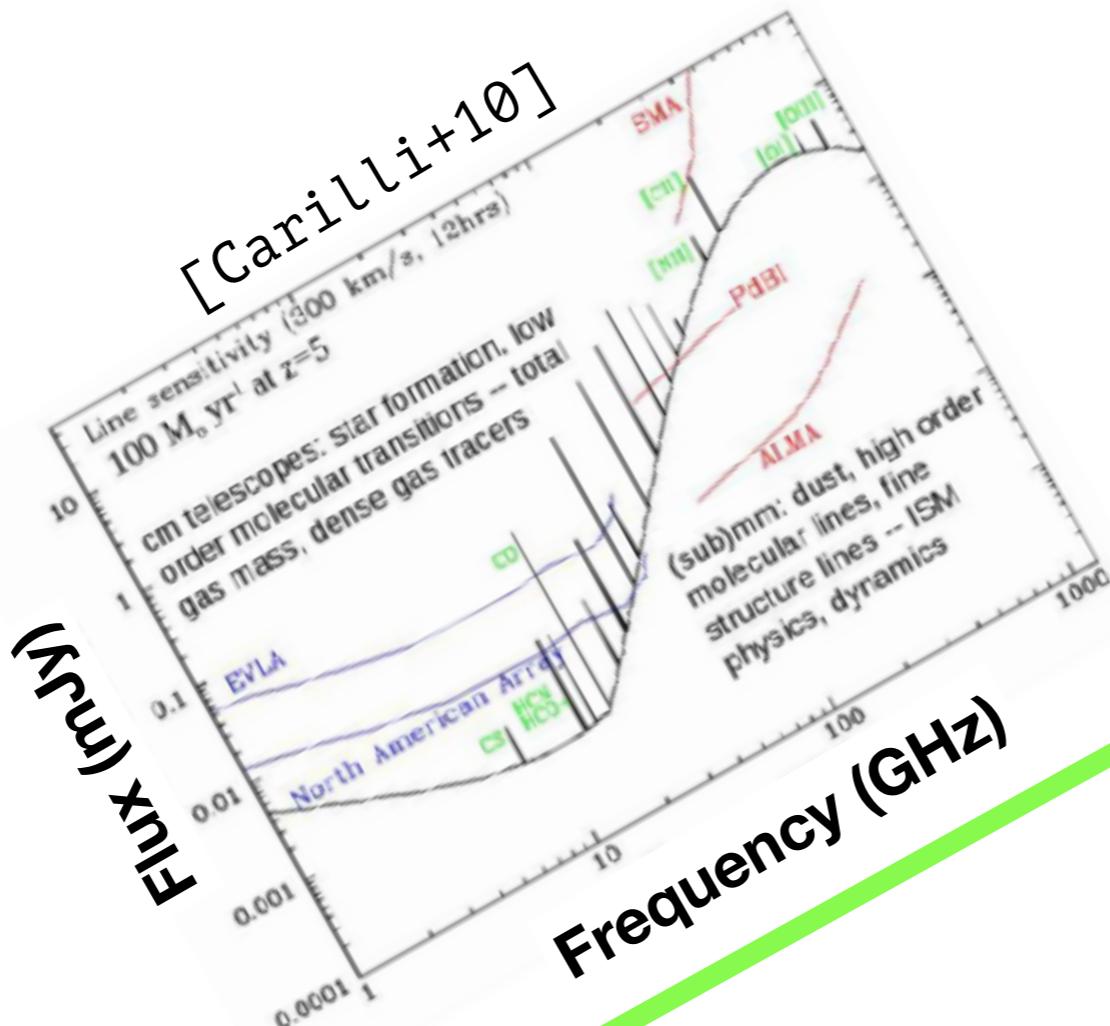
2) Using Simulations to go
back in time!

What far away galaxies look like in the telescope



GN-z11 is the most distant galaxy observed to date, just 400 million years after the Big Bang!

Spatially => spectroscopically

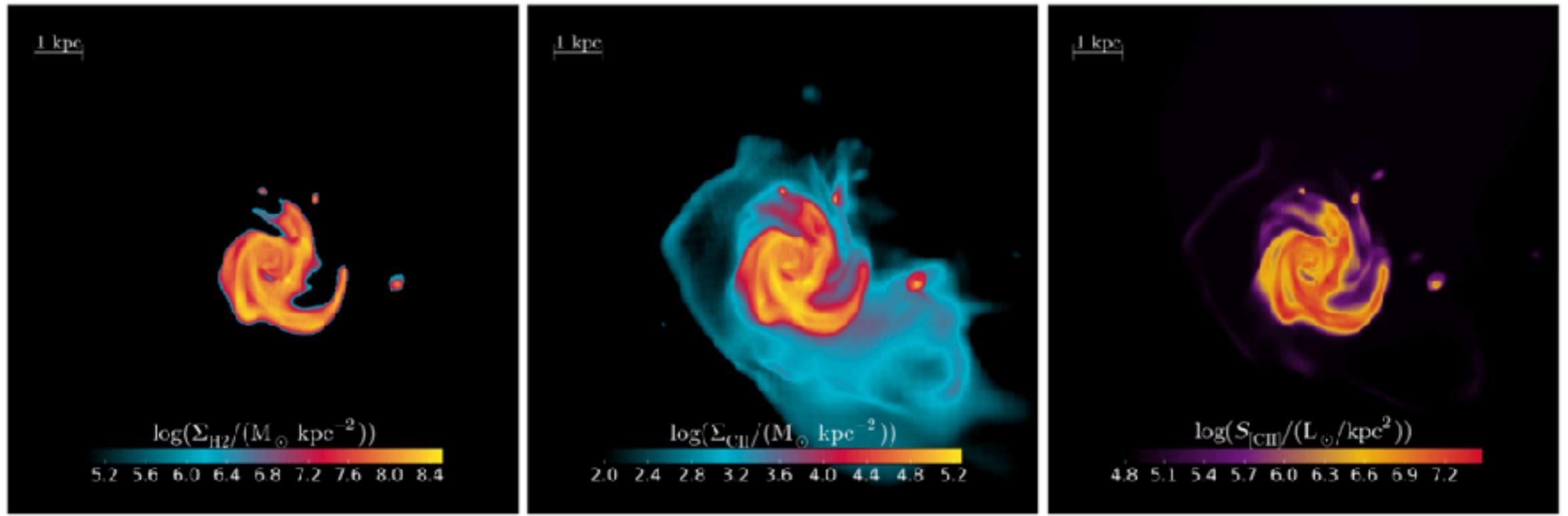


Simulating one emission line at a time...

[CII] = an emission line from singly-ionized carbon atoms in the ISM.

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MOLECULAR GAS
in a typical $z \sim 6$ galaxy
(almost 1 Gyr after Big Bang)

Singly-ionized carbon (C⁺)

[CII] emission