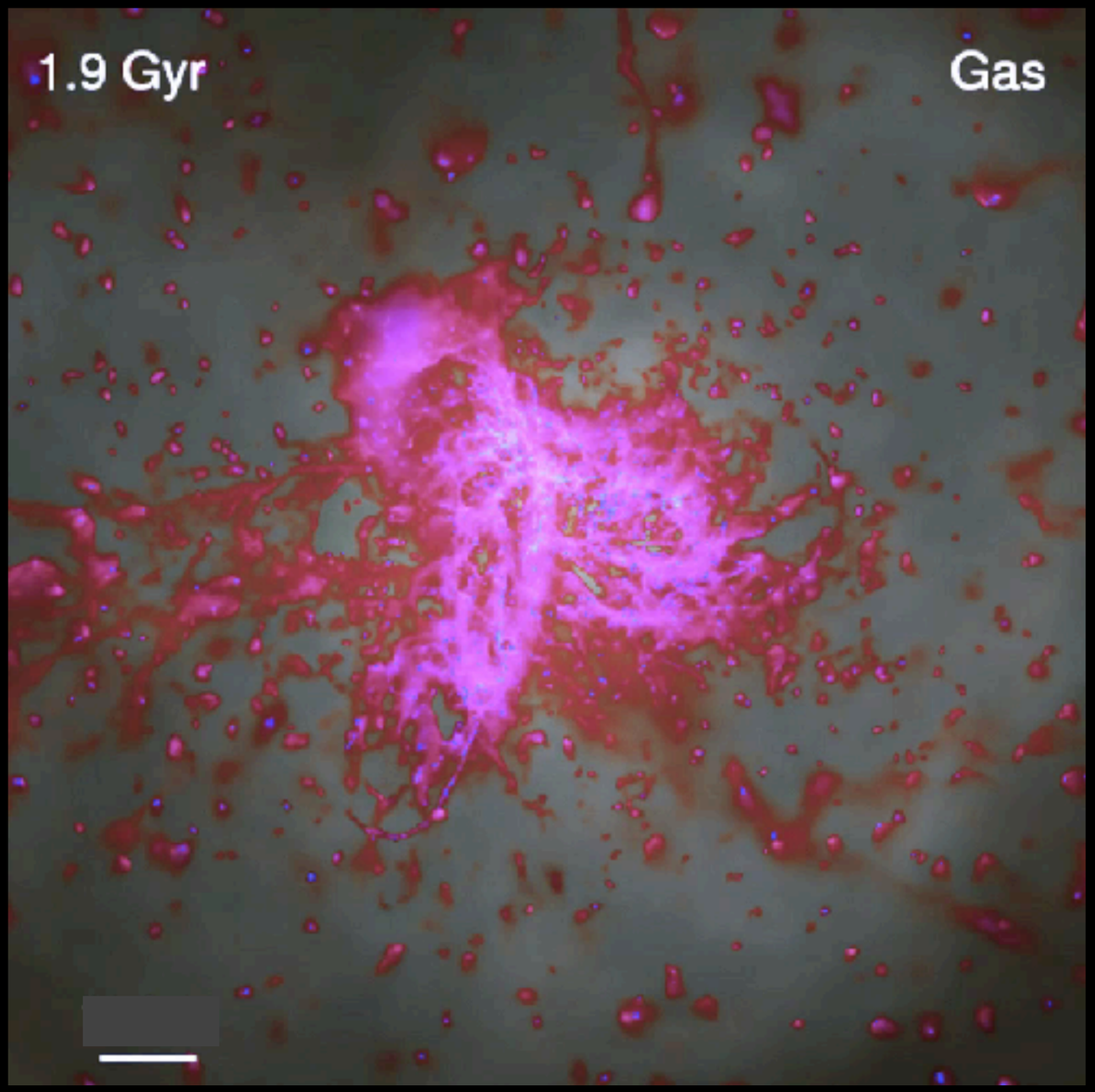
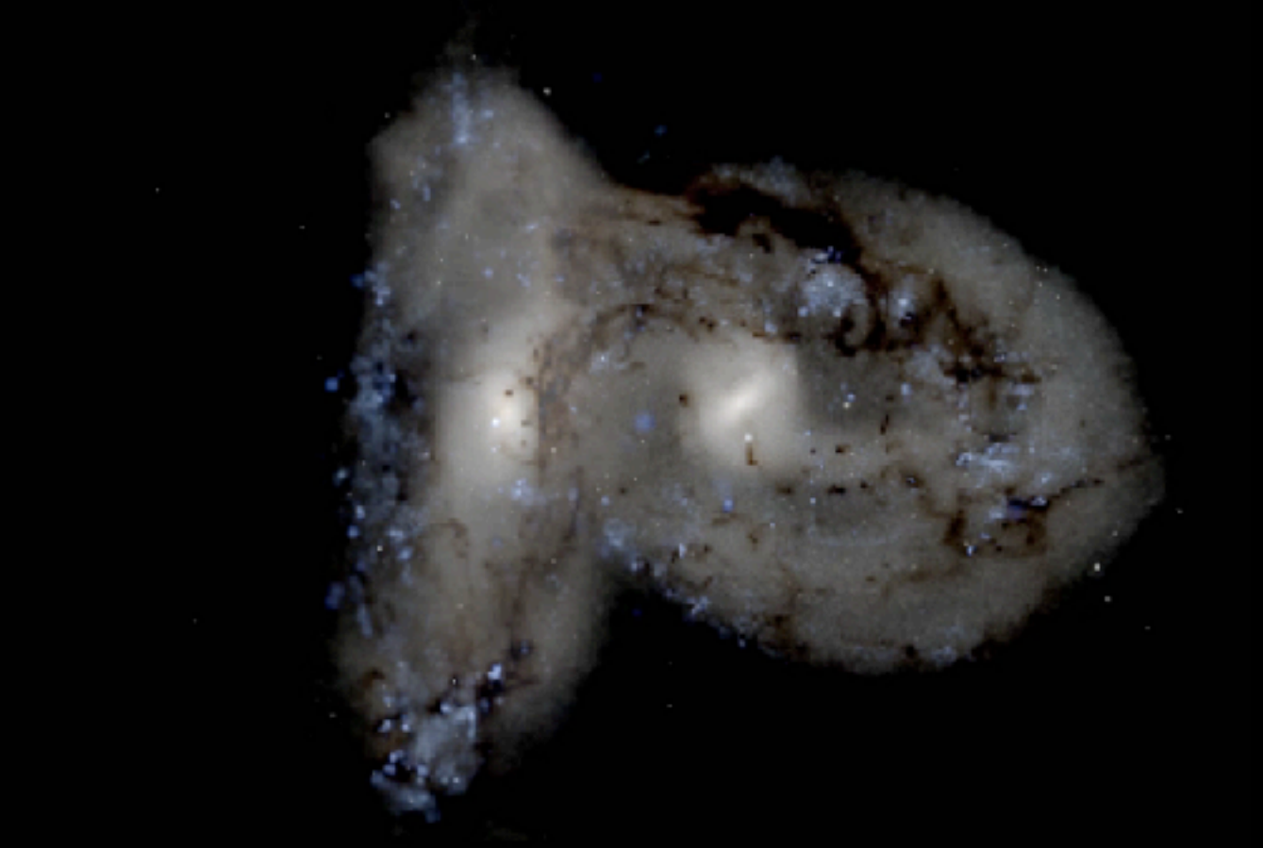
The Universe on a Computer





30,000 light-years

Philip Fajardo Hopkins

Caltech (California Institute of Technology), Astronomy & Astrophysics

www.tapir.caltech.edu/~phopkins

Last time I was here…

Postdocs

Robyn
Sanderson

Anne
Medling

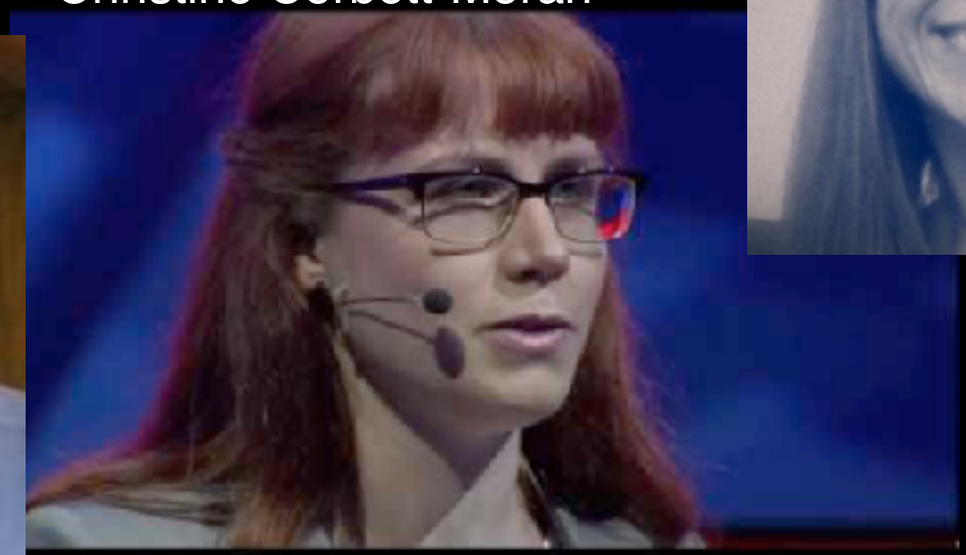
Daniel
Angles-Alcazar

Coral Wheeler

Lina Necib

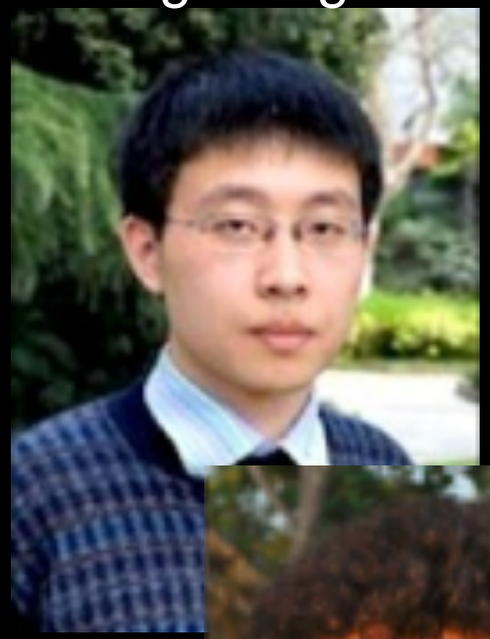
Ji-Hoon
Kim

Christine Corbett-Moran



Grad Students

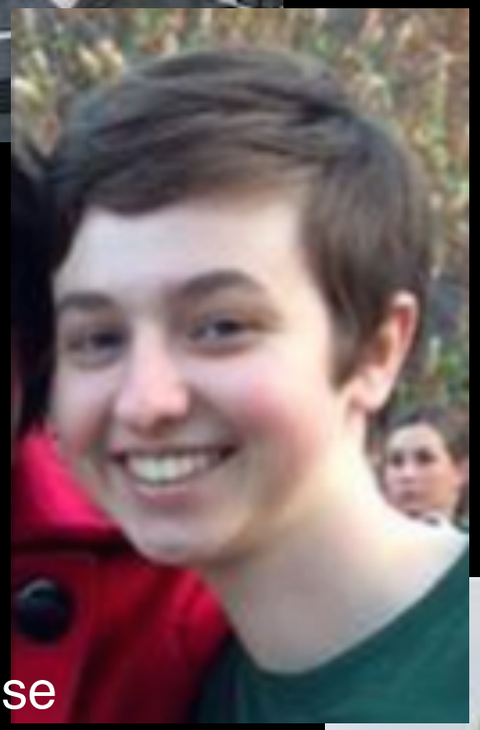
David Guszejnov



Xiangcheng Ma

Matt Orr

Mike Grudic

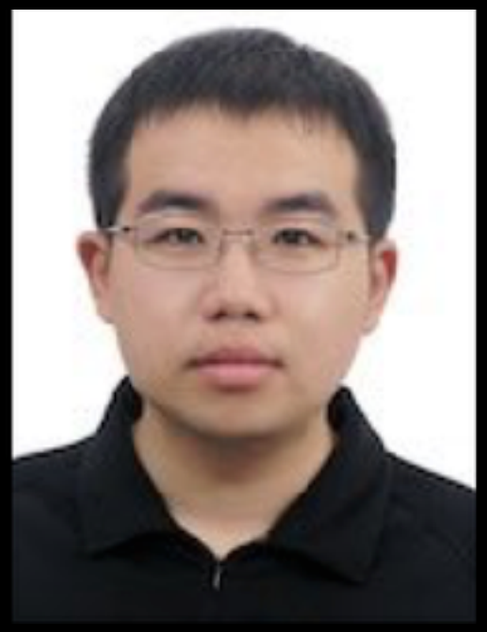


Denise Schmitz

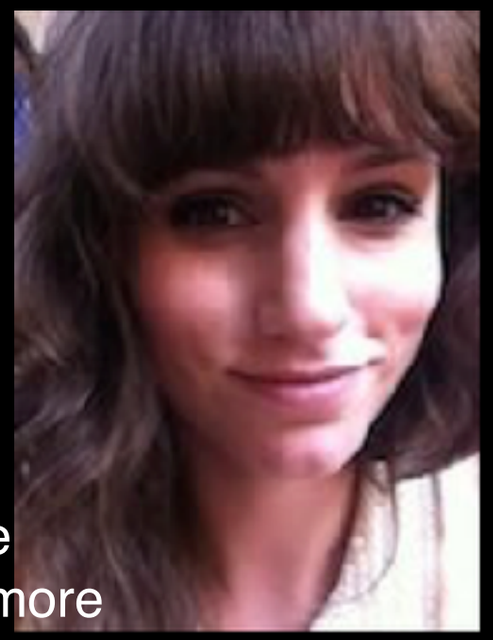
Kareem El-Badry

Ivanna Escala

Antonija Oklopcic



Kung-Yi Su

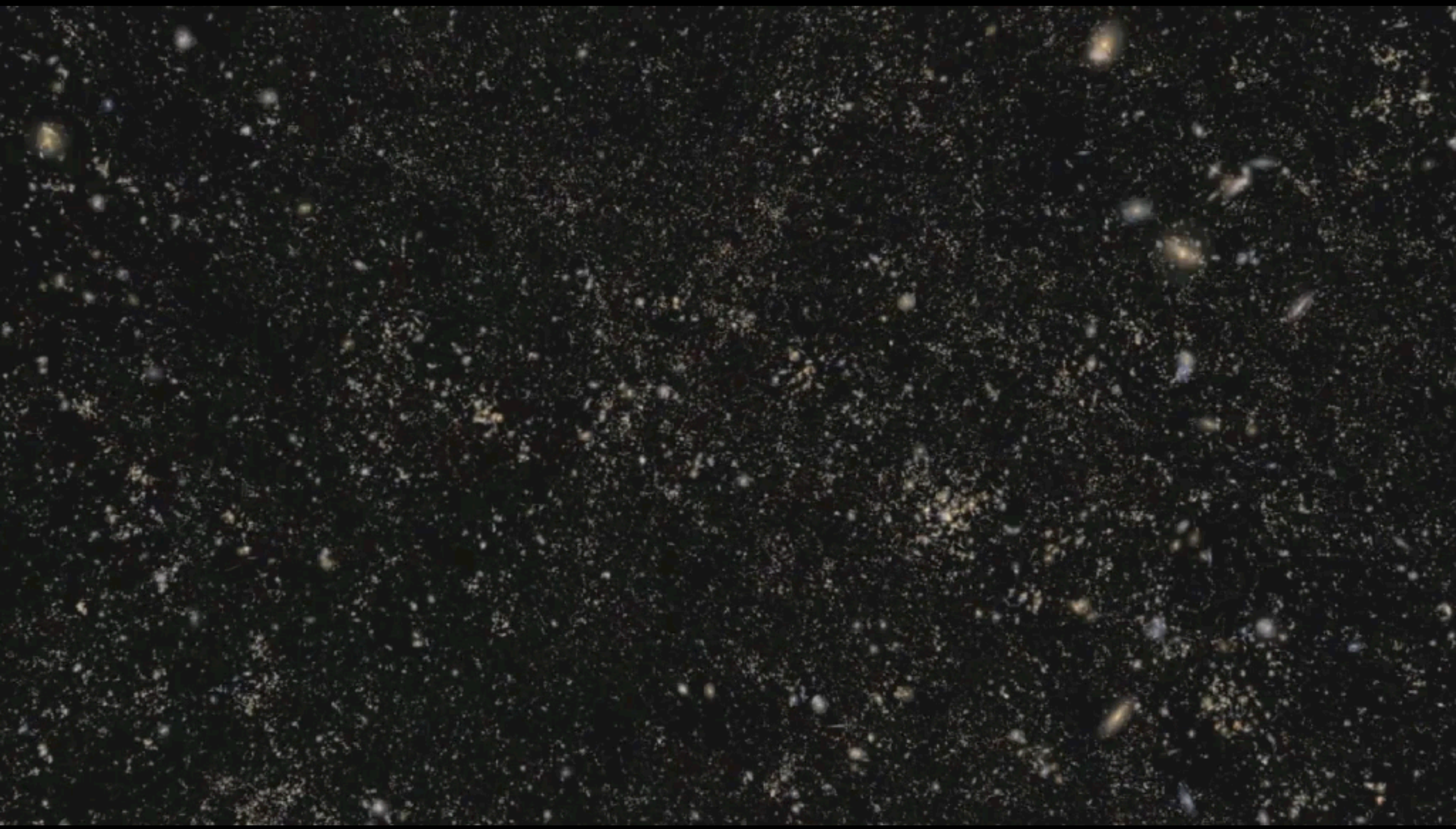


Hannalore Gerling-Dunsmore

Where (and what)
are we?

What's a Universe?

Today (13,700,000,000 yrs old)

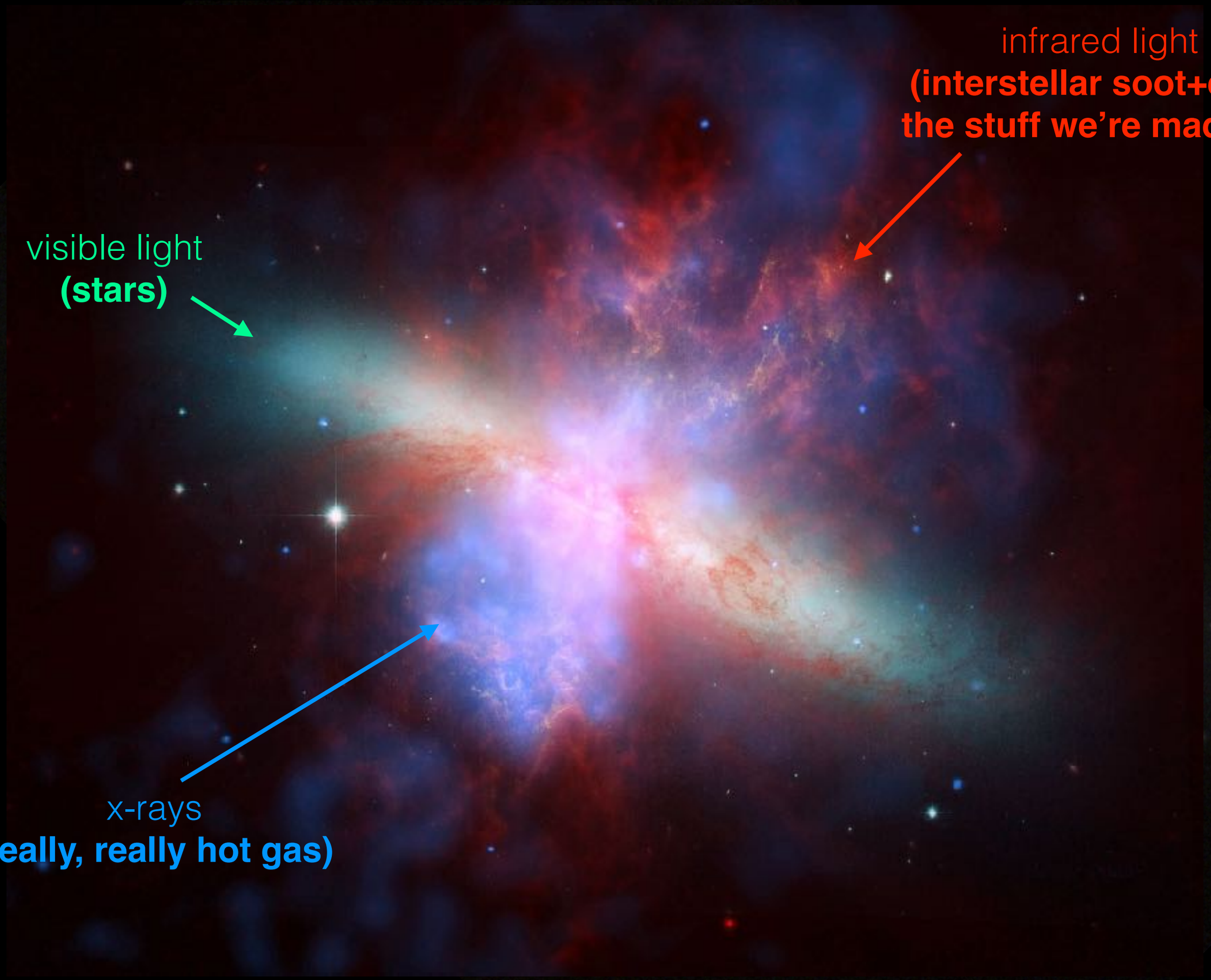


(movie: Sloan Digital Sky Survey; Miguel Aragon)

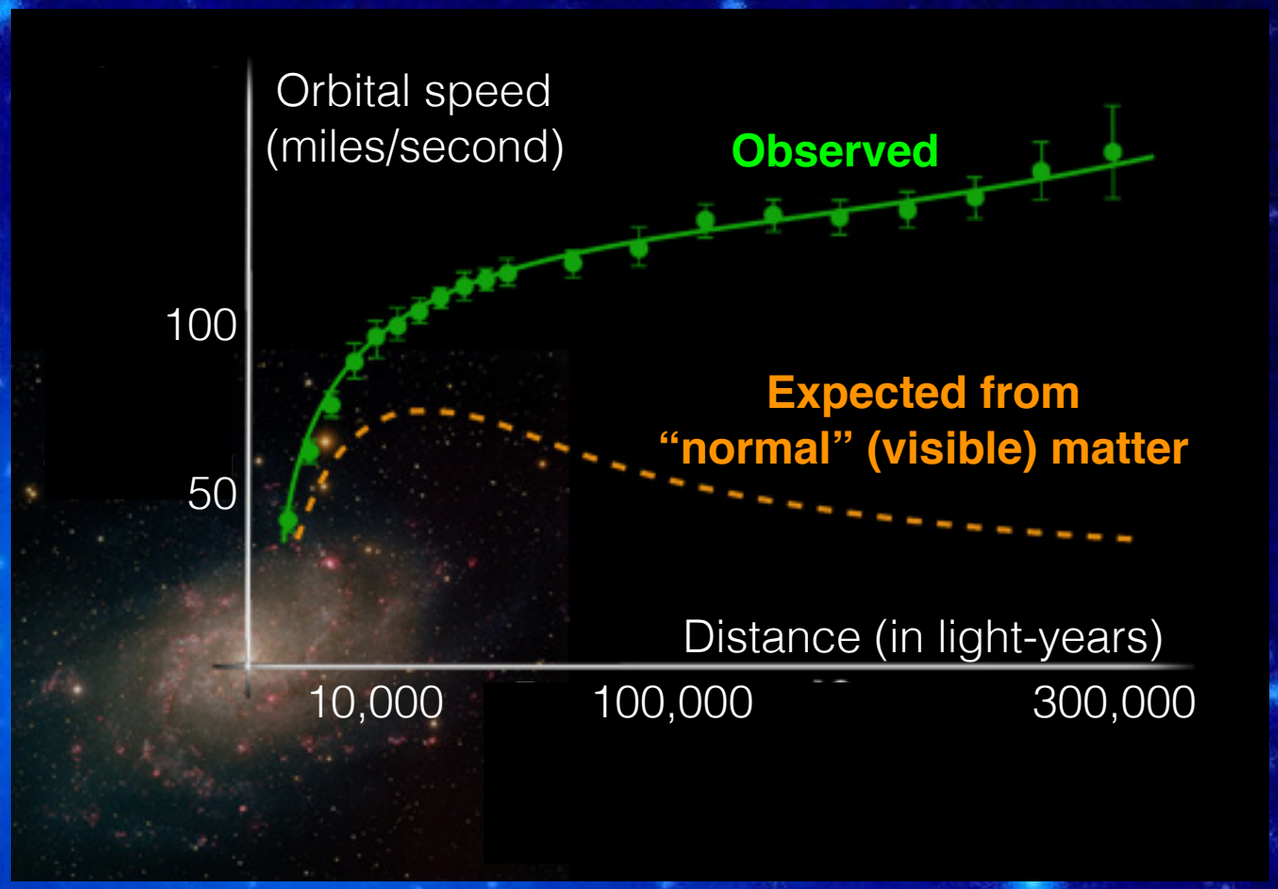
(flying at 400 *trillion* times the speed of light)

Plus…

What we can't see *with our eyes…*



And what we *just can't see…*

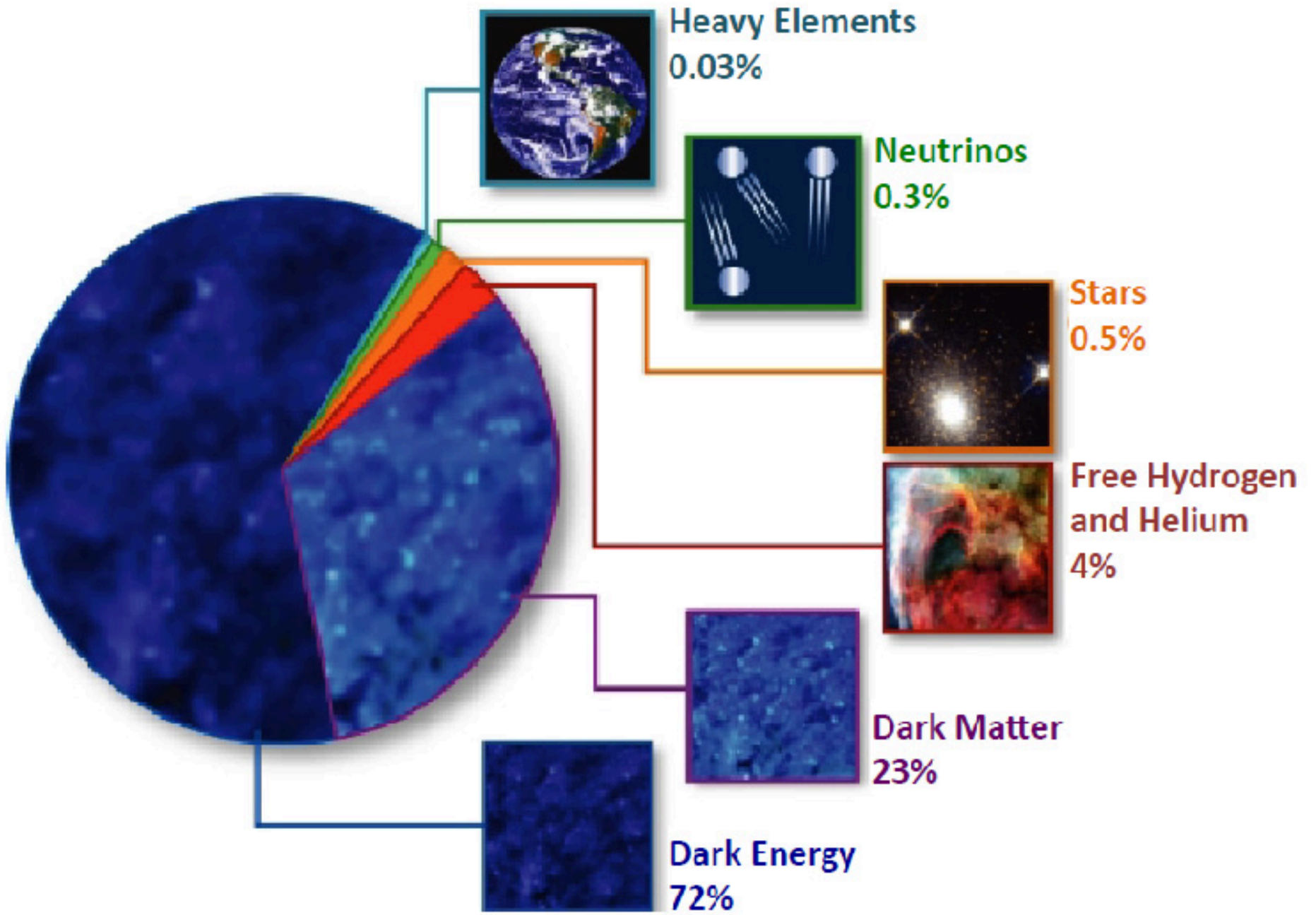


(dark matter)

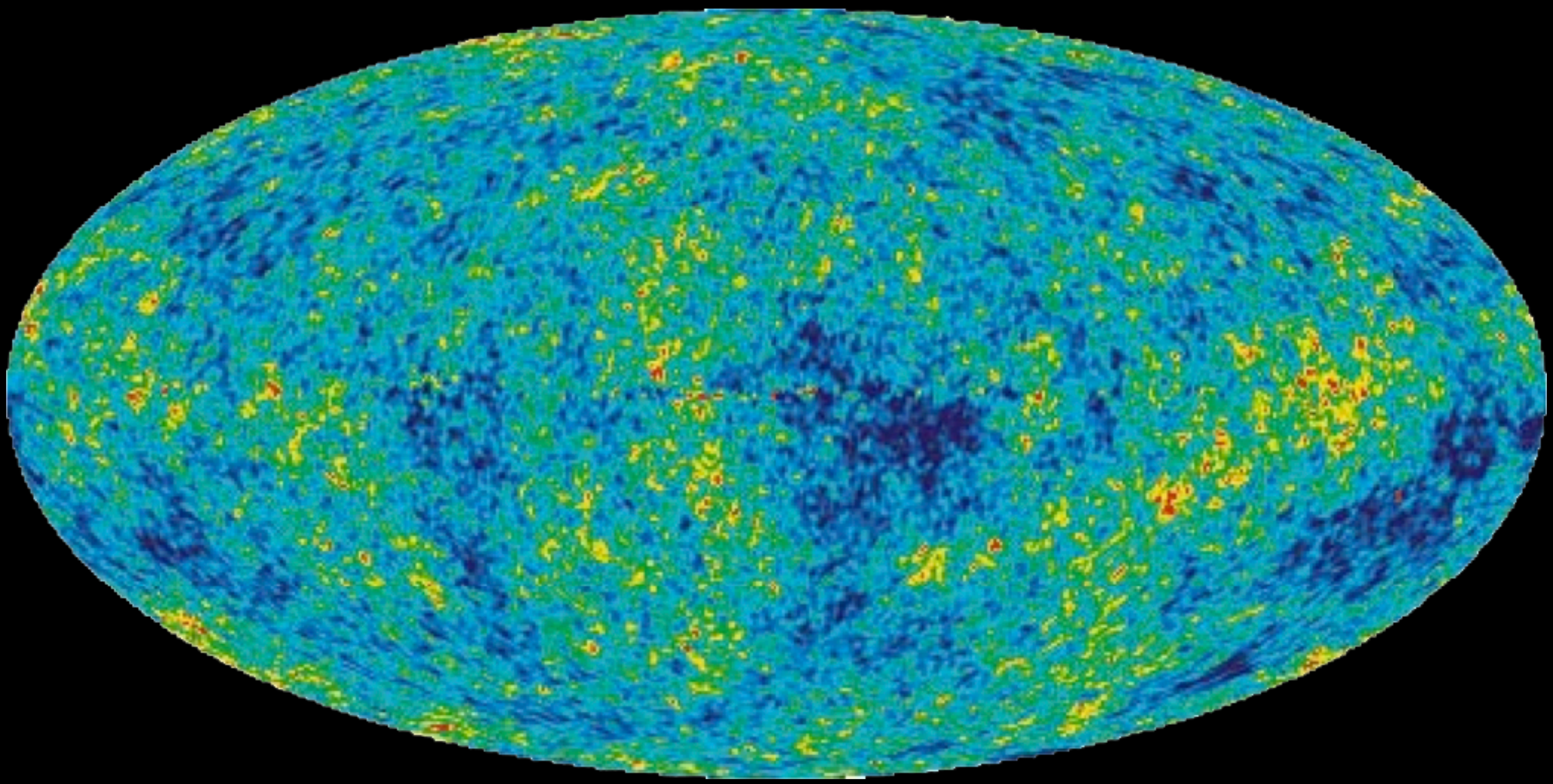
1,600,000 light-years

So what is the
“recipe”?

Composition of the Cosmos (ingredients)



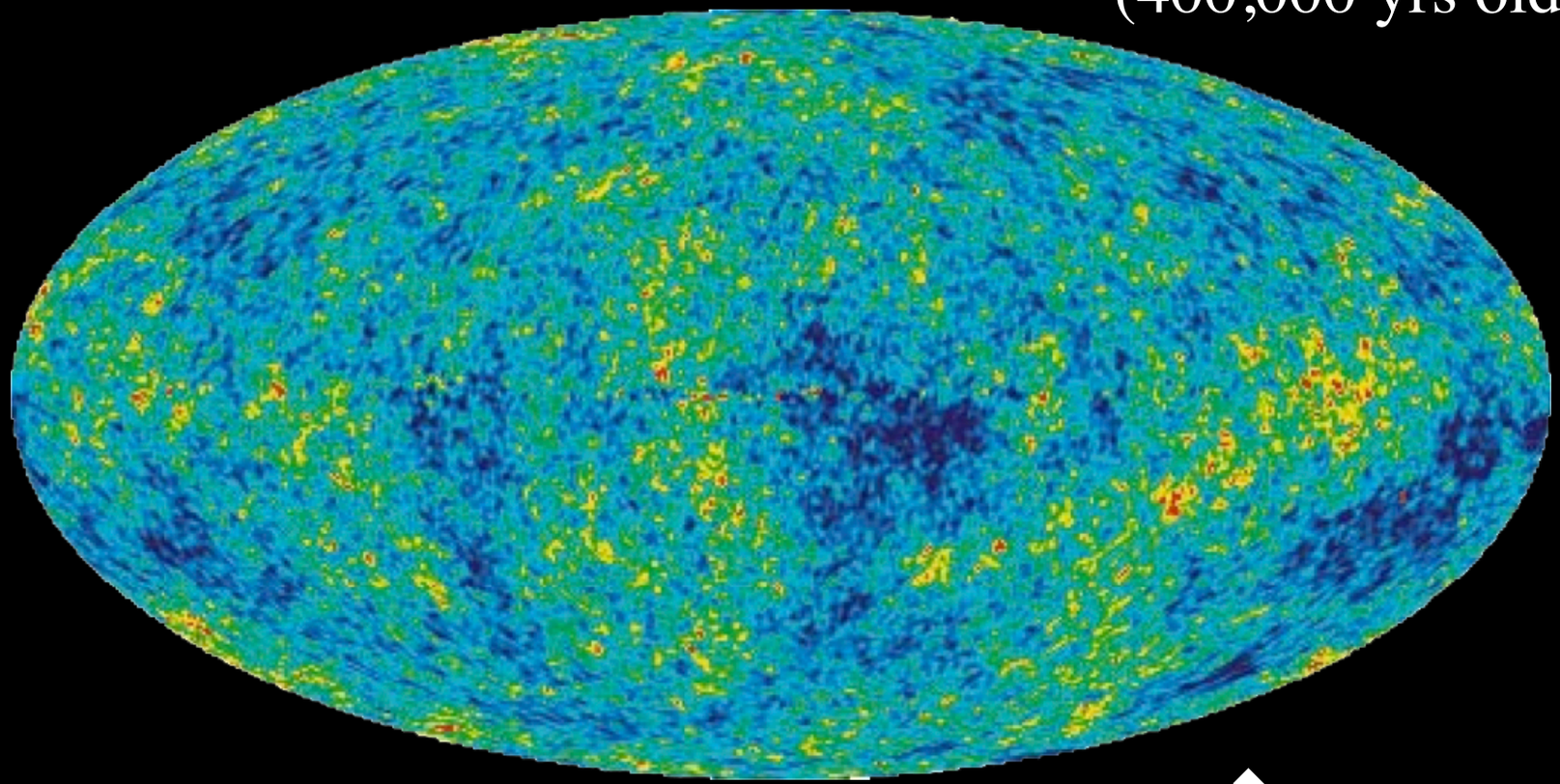
Our Universe's Baby Picture:



+0.0001% more dense
-0.0001% less dense

(Planck satellite)

(400,000 yrs old)



?

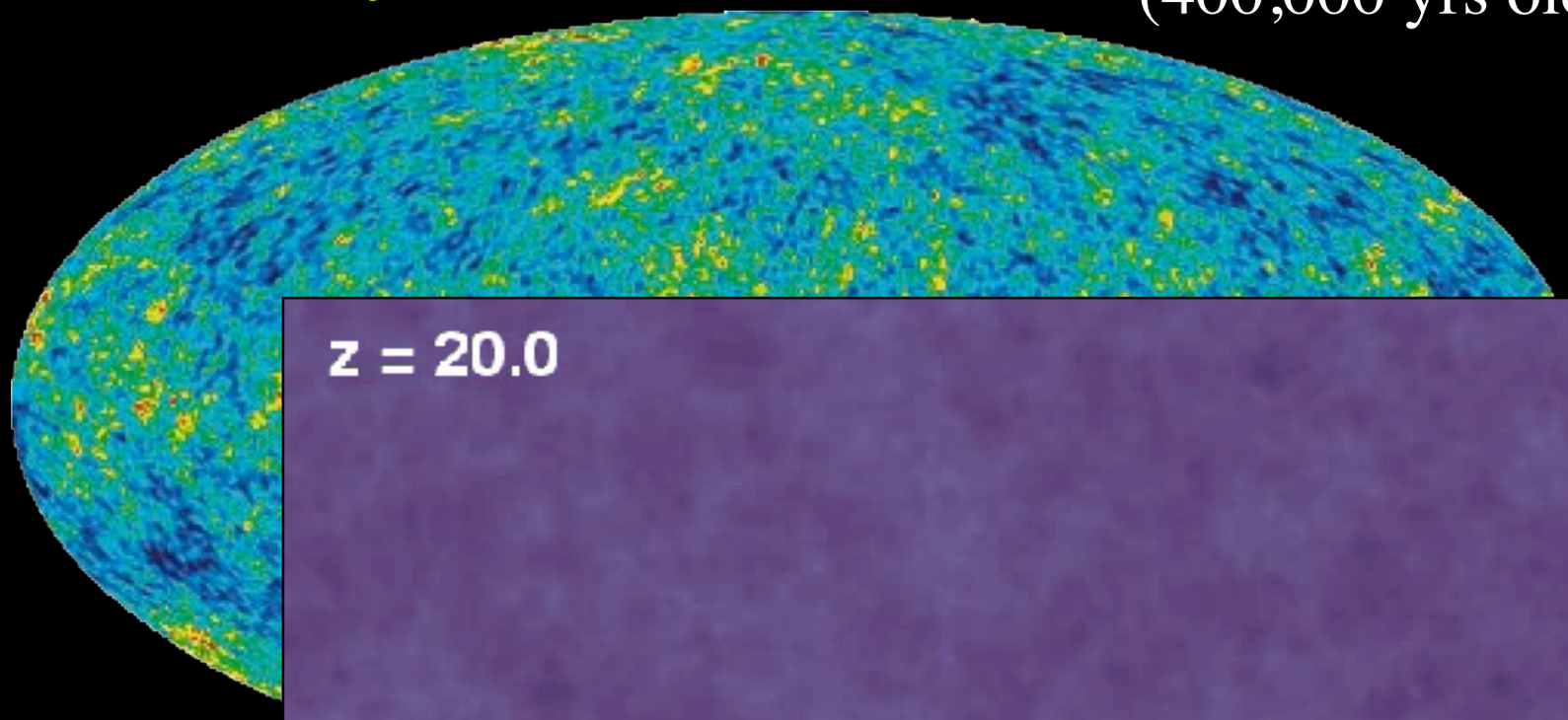
(13,700,000,000 yrs old)

Gravity:

$$\text{acceleration} = \frac{G \times \text{Mass}}{\text{distance}^2}$$

Add Gravity and "Cook"

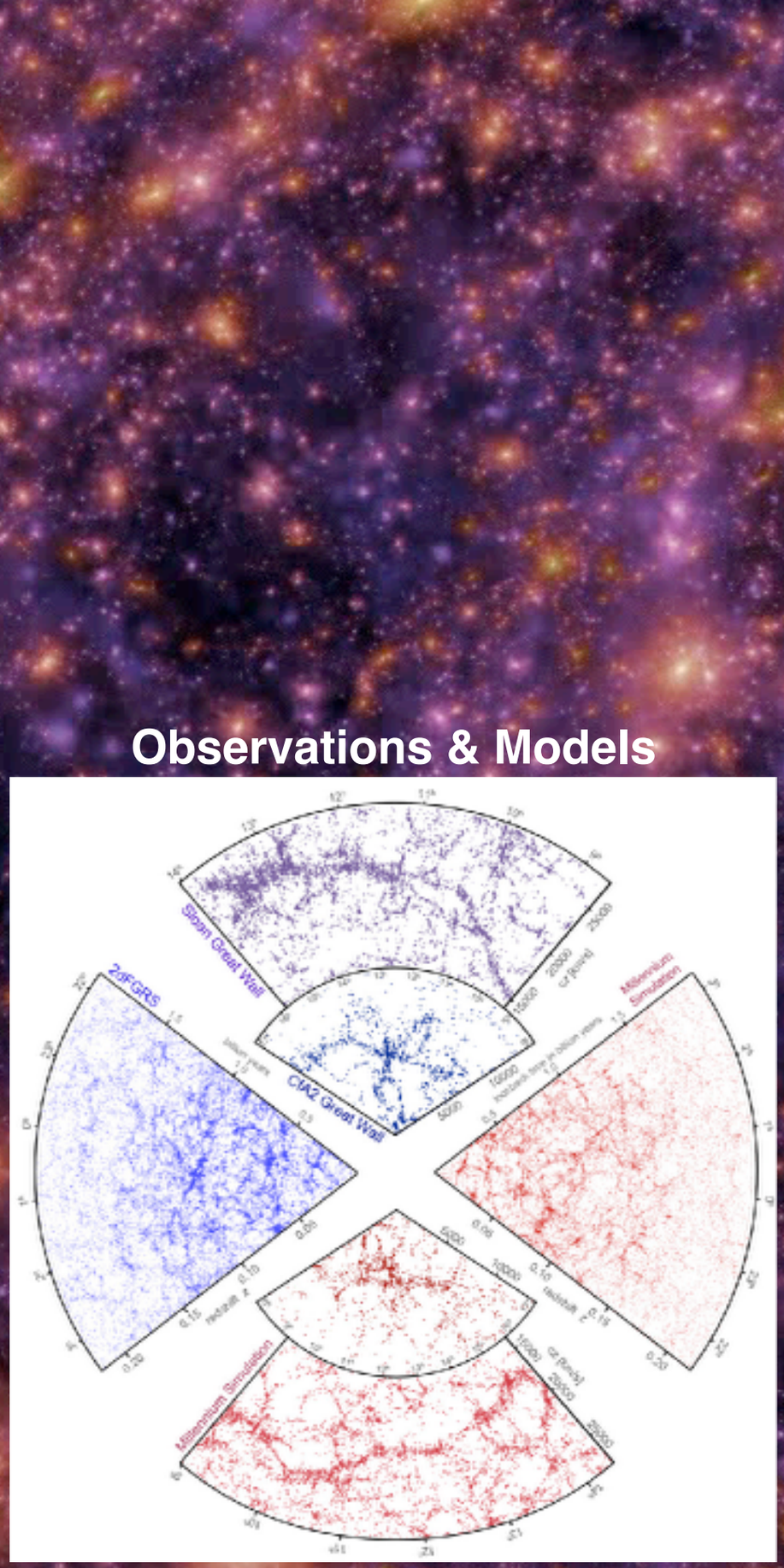
(400,000 yrs old)



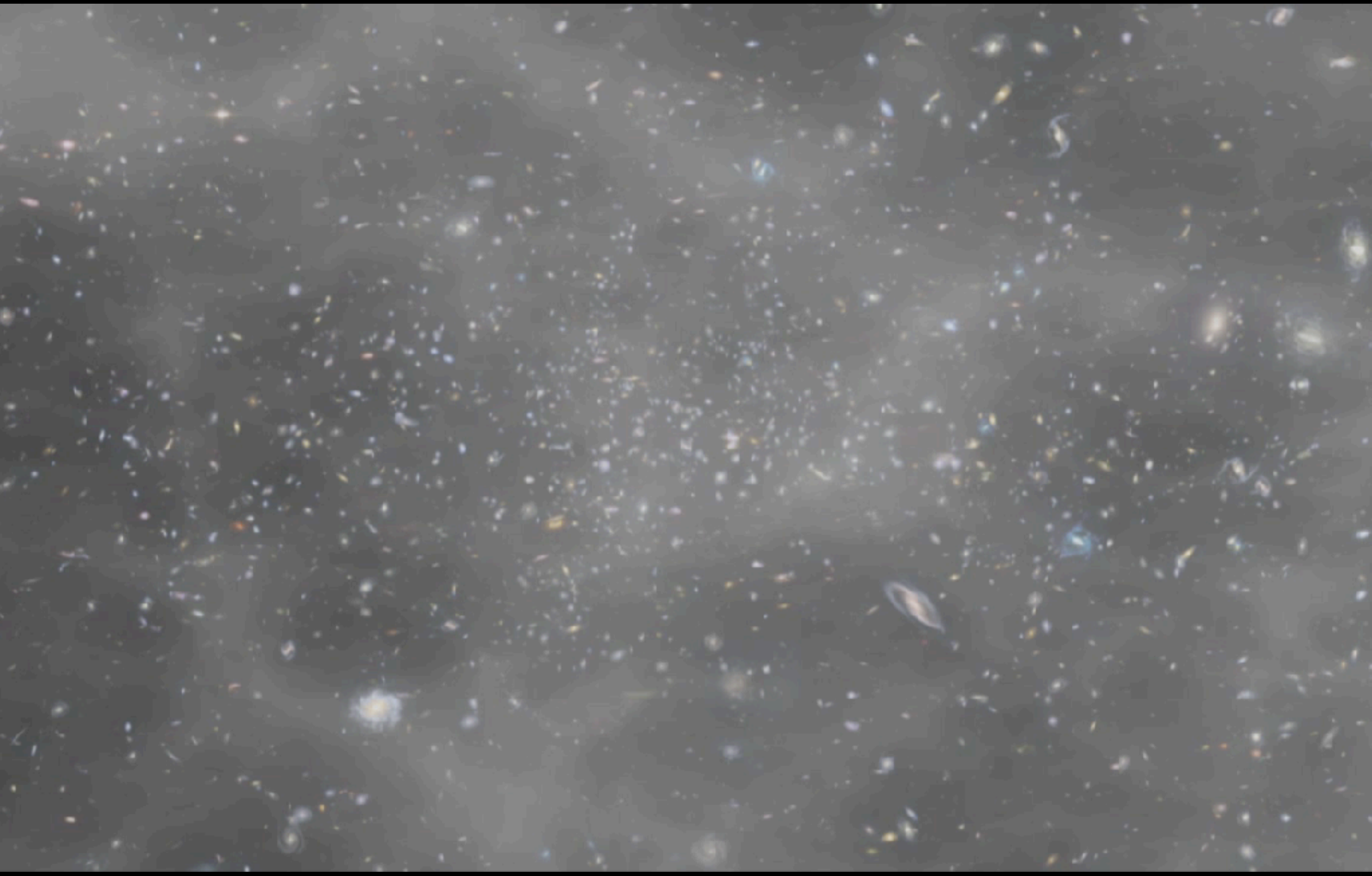
,000 yrs old)

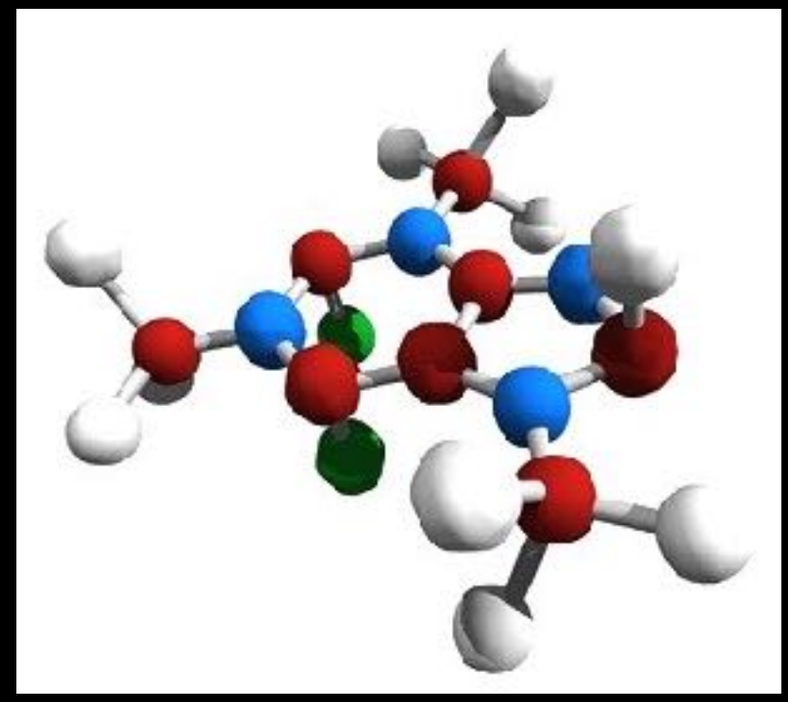
The "Cosmic Web"

Observations & Models



Paint some galaxies on there…





Add some fluid dynamics and chemistry, and go!

~10-100 billion light-years

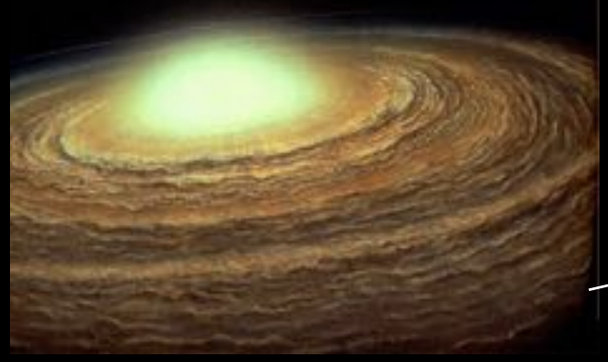
the visible Universe

~10-100 million light-years

groups of Galaxies

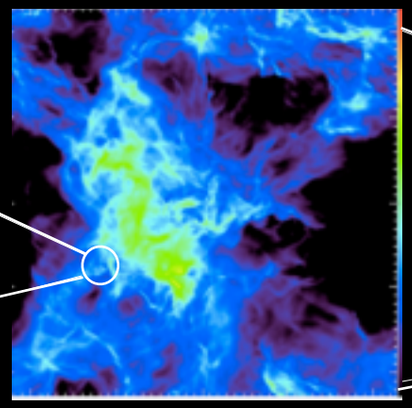
~10-100 thousand light-years

a Galaxy



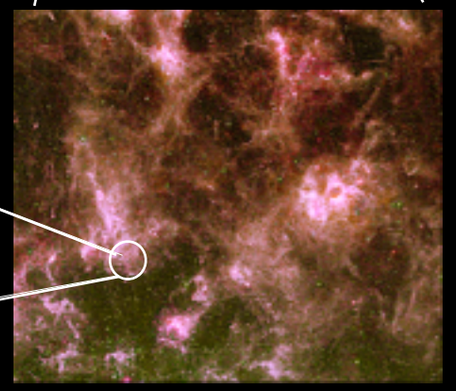
~0.00001 light-years
(50 million miles)

Solar systems



~0.01-1 light-years

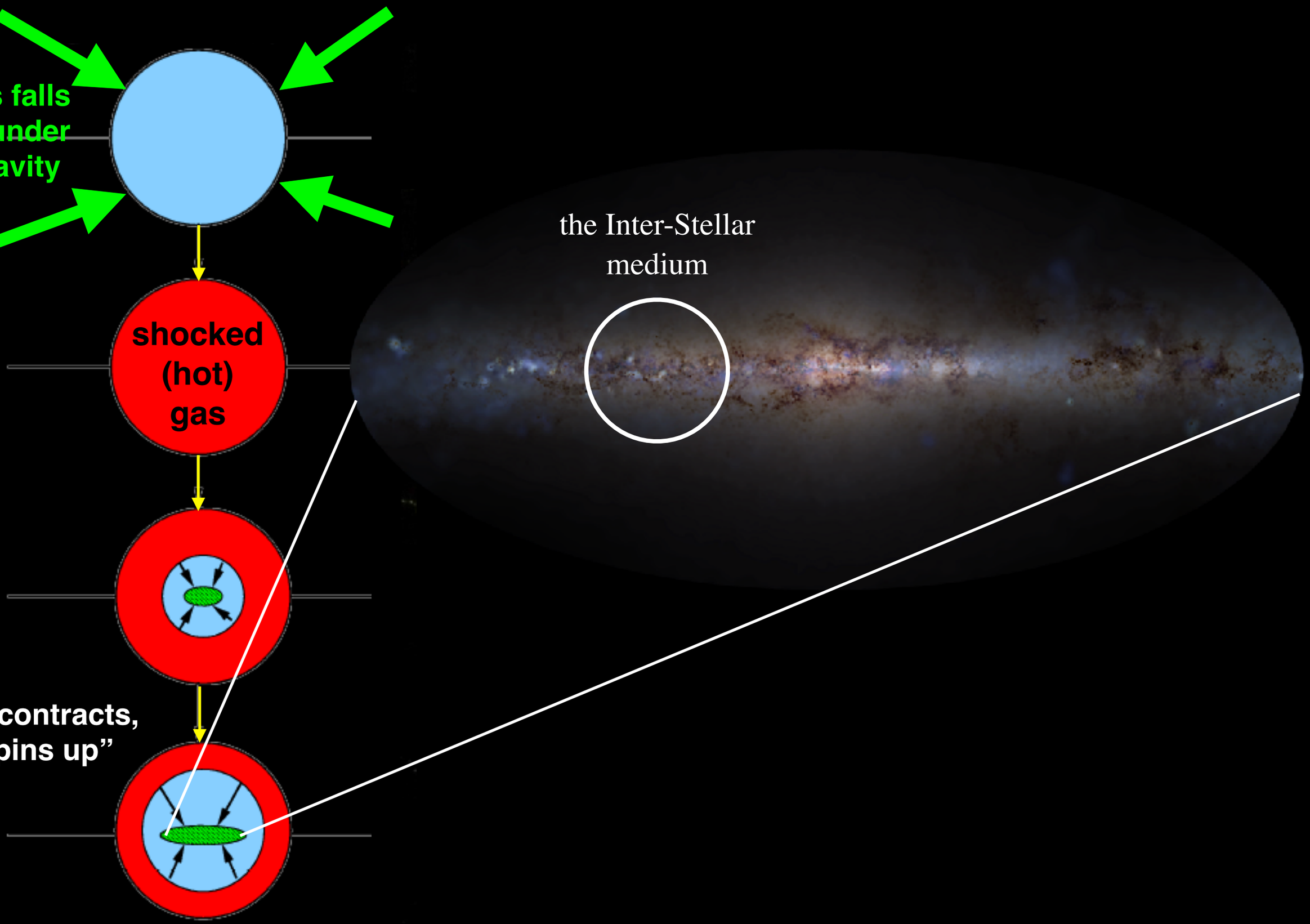
groups of Stars,
gas “clumps” contracting to stars



~10-100 light-years

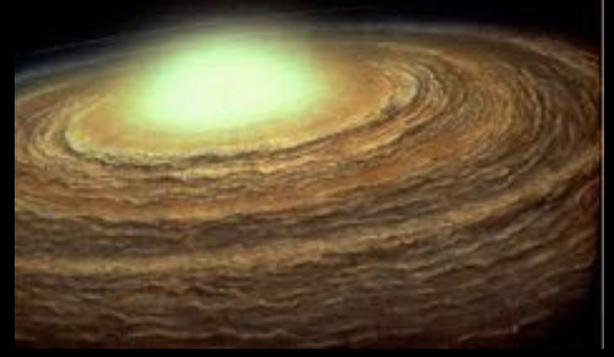
the Inter-Stellar
Medium (clouds forming stars)

The Basic Picture



Repeat: the Inter-Stellar Medium

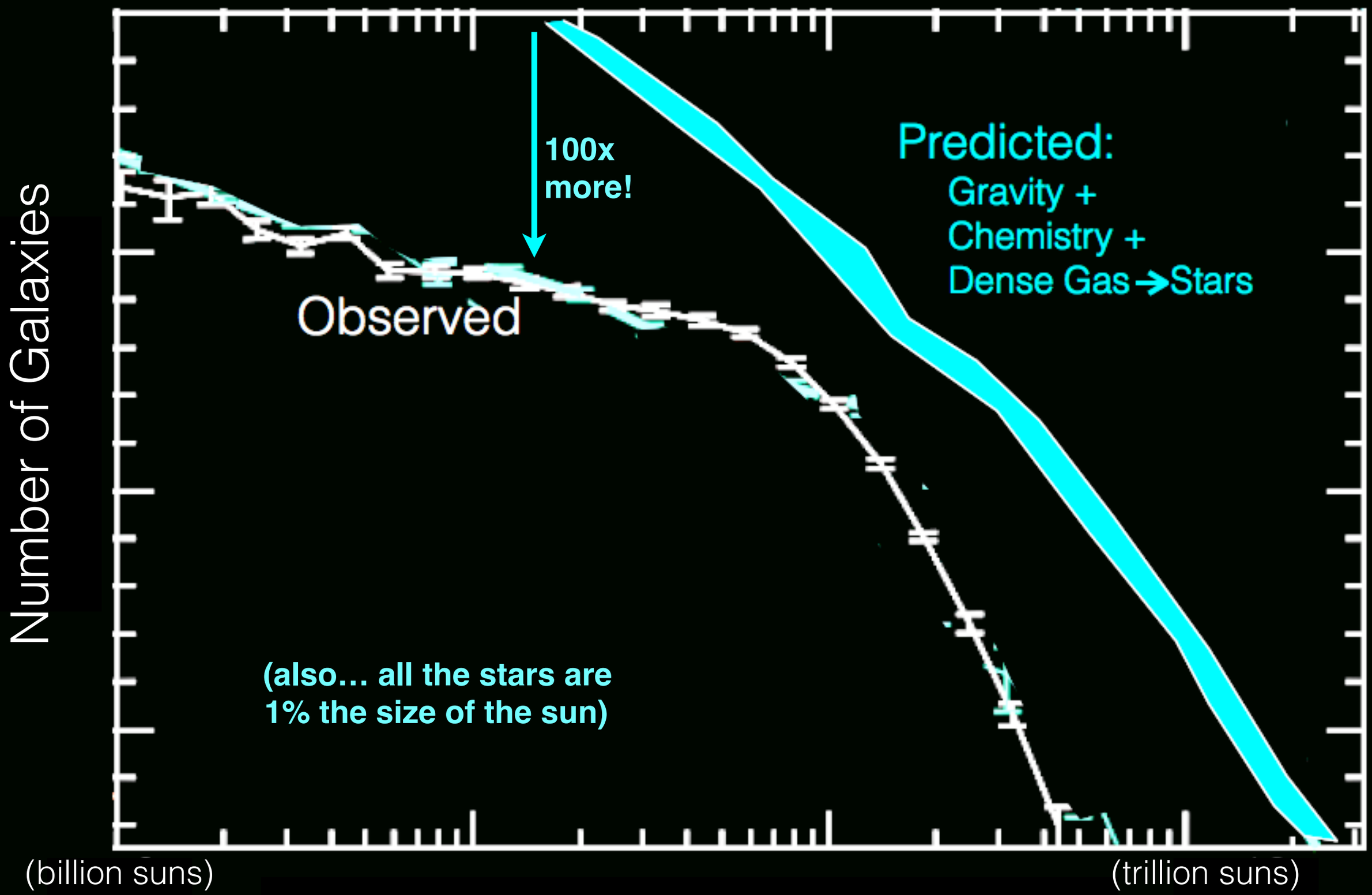
Repeat: Star & Planet Formation



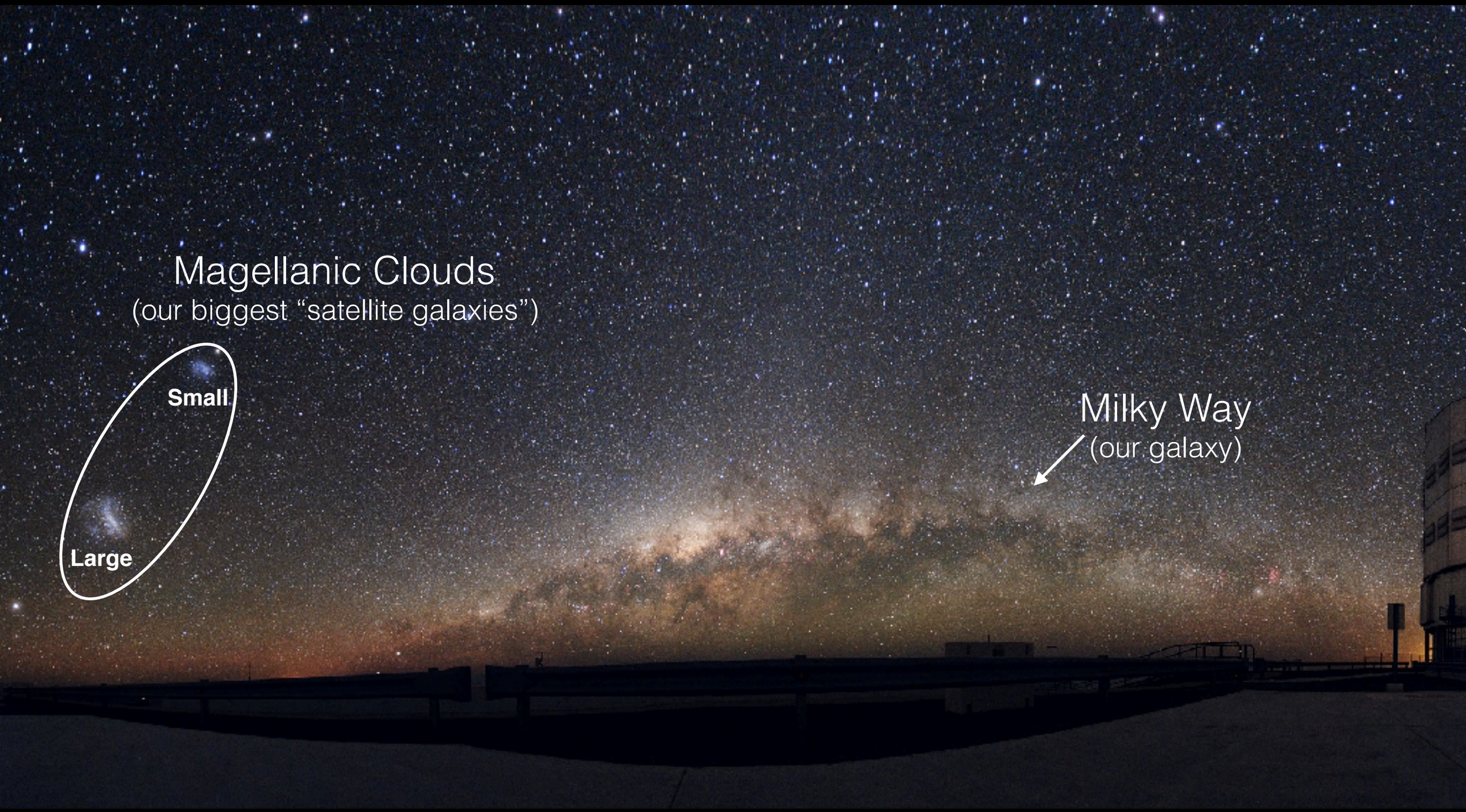
Done!

Not so fast…

Problem: Why so few galaxies and stars?



Problem: Why so few galaxies and stars?



What did we miss?

Stars *shine*

our sun

an “O-star”
(1,000,000x brighter)

R136a1

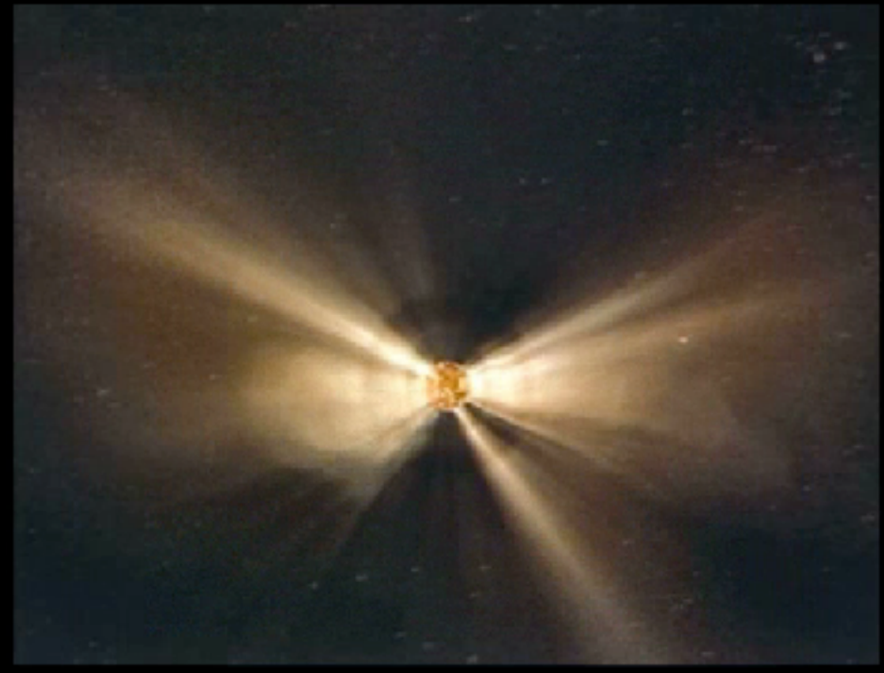
Stars *shine*

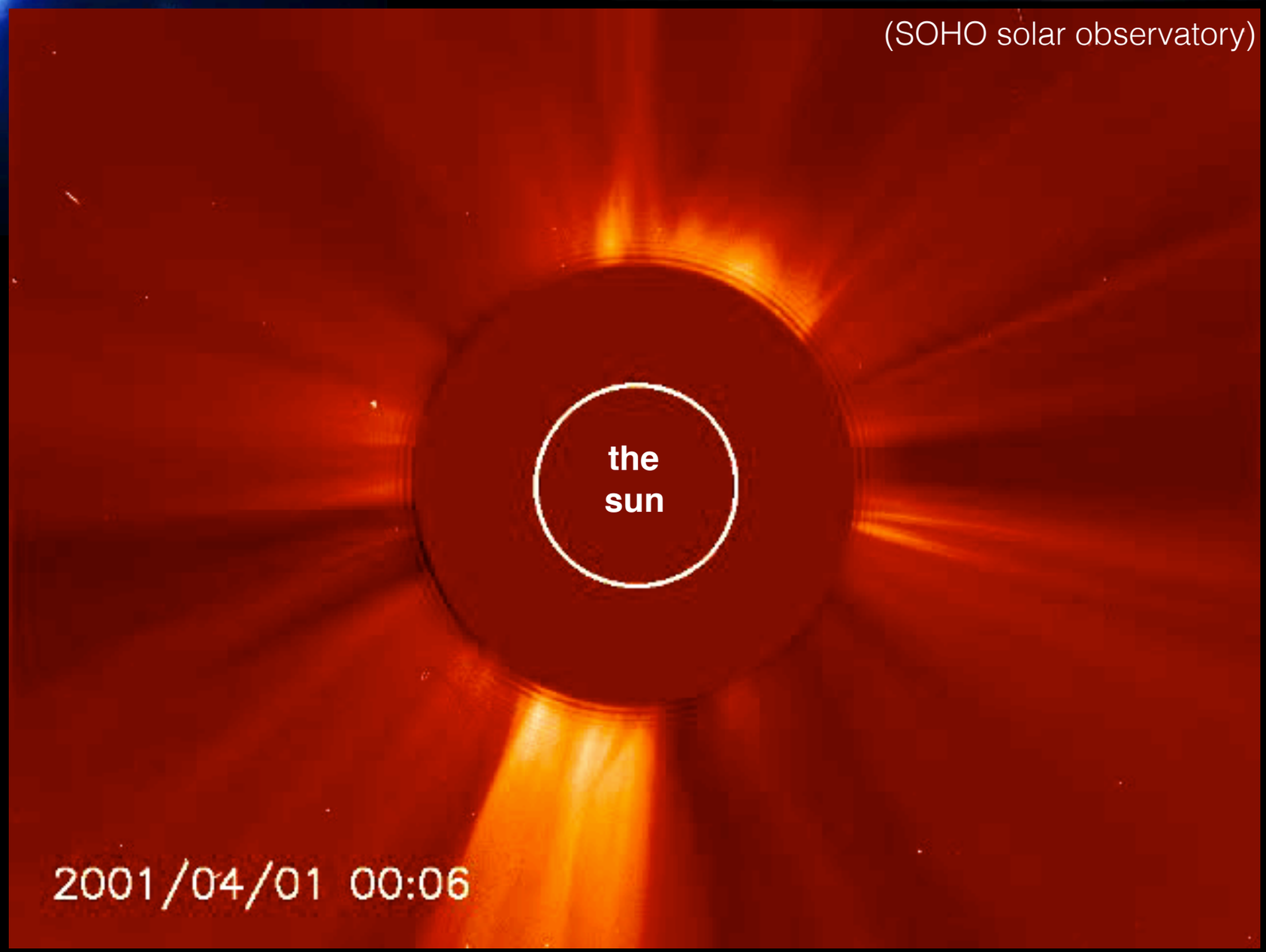
our sun

an “O-star”
(1,000,000x brighter)

(4-year timelapse of a “light echo” around a star)

Stars *blow*

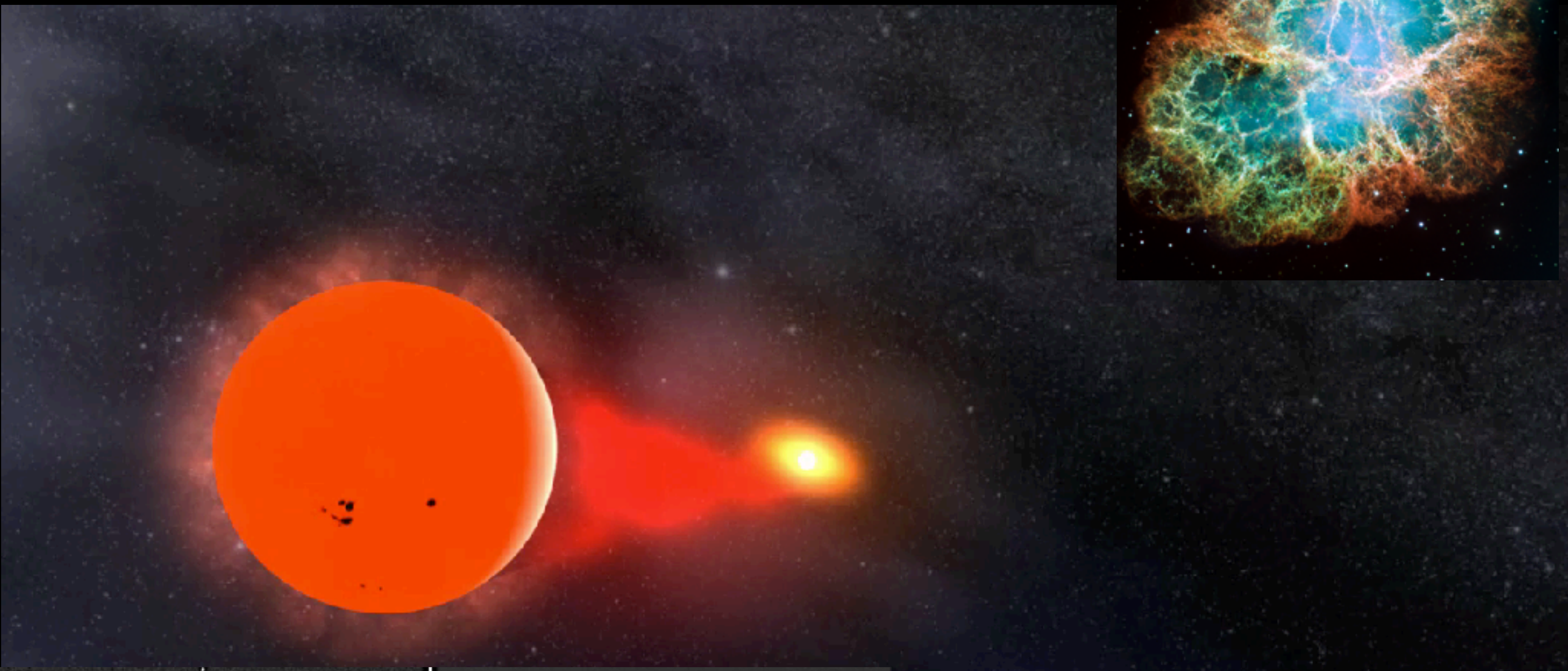


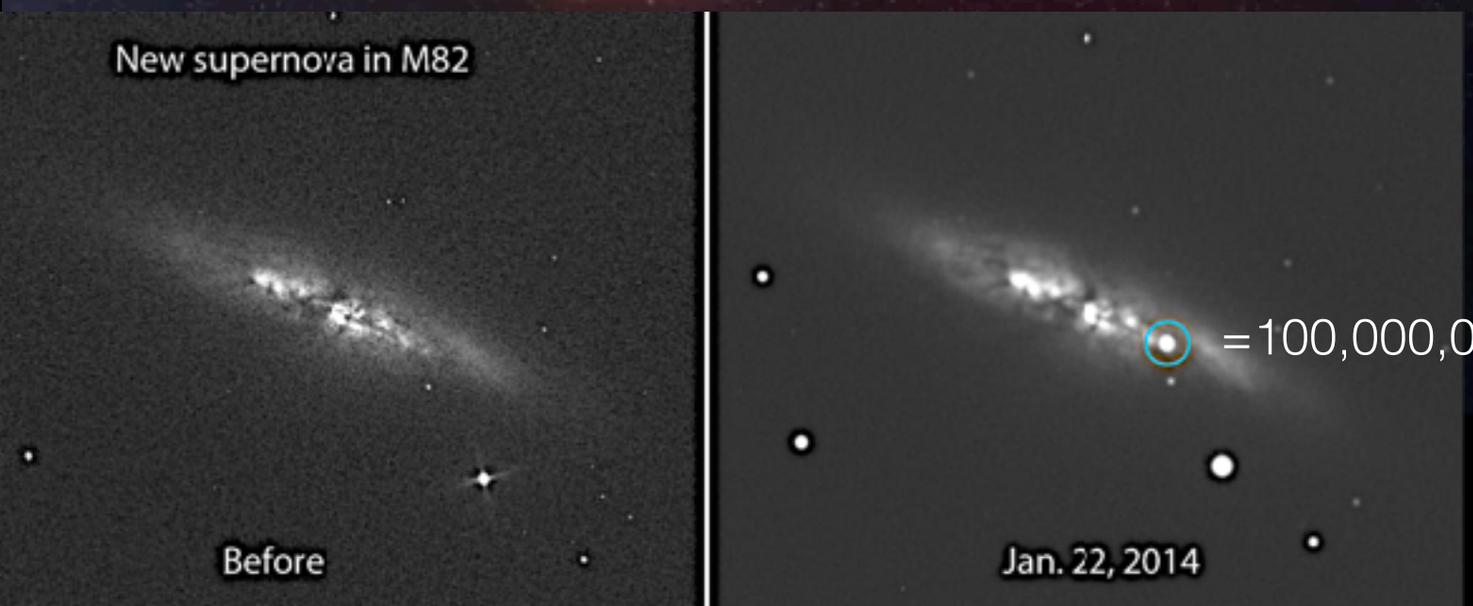


(SOHO solar observatory)

Stars *explode*

Crab Nebula
(exploded 1054 AD)

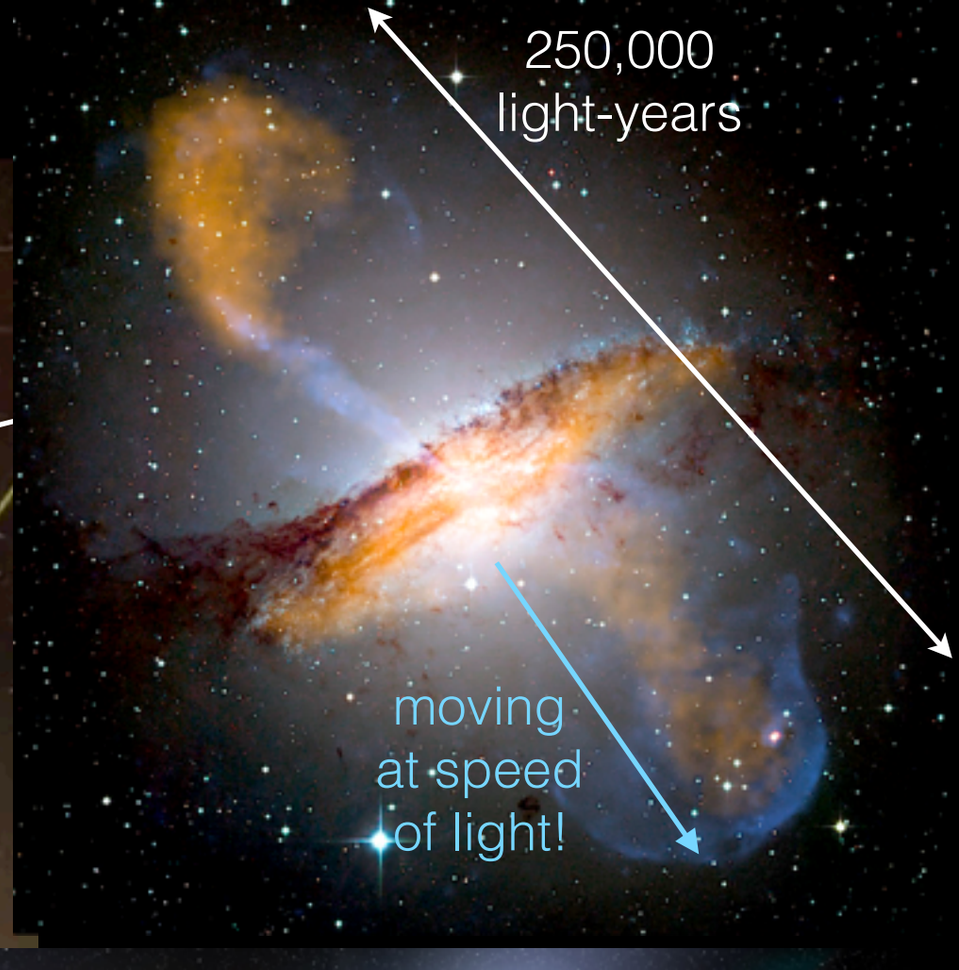


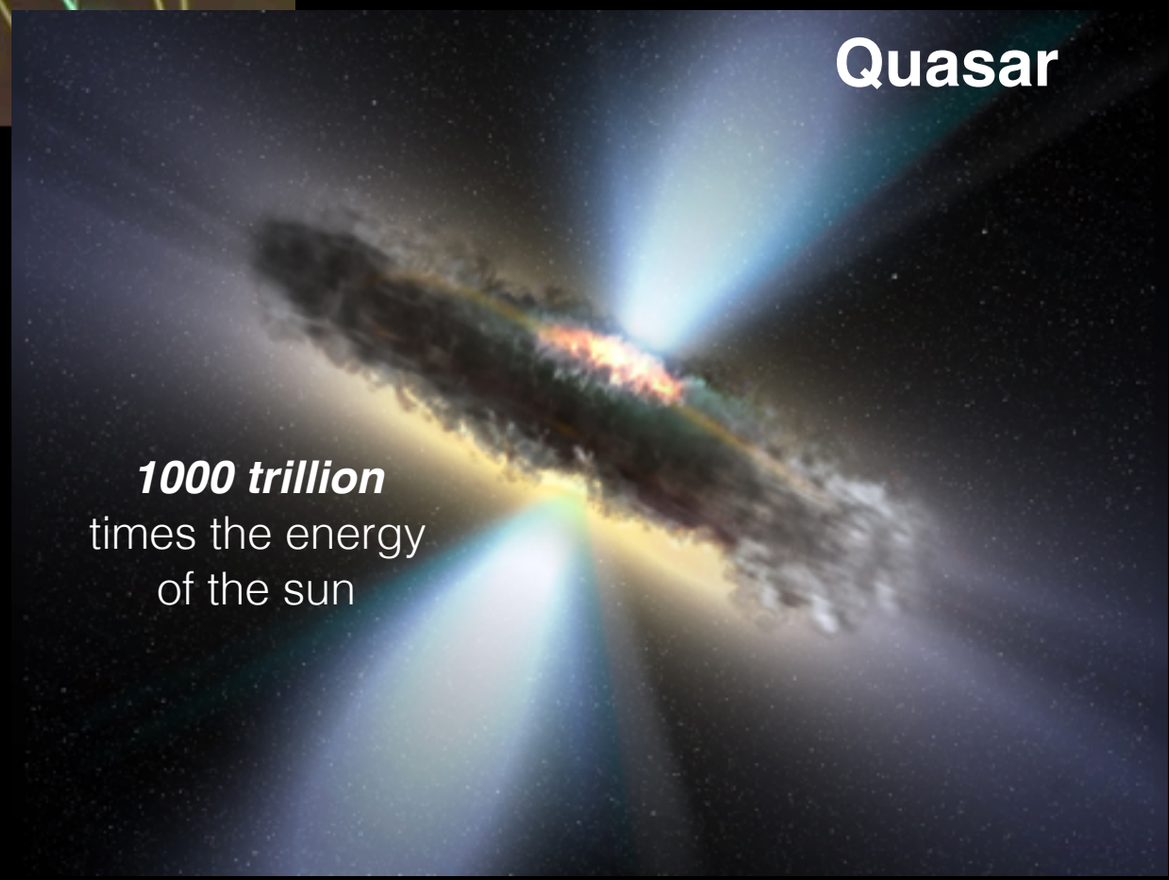


=100,000,000,000 stars

It gets even crazier…

stars in the center of our galaxy (2004-today)

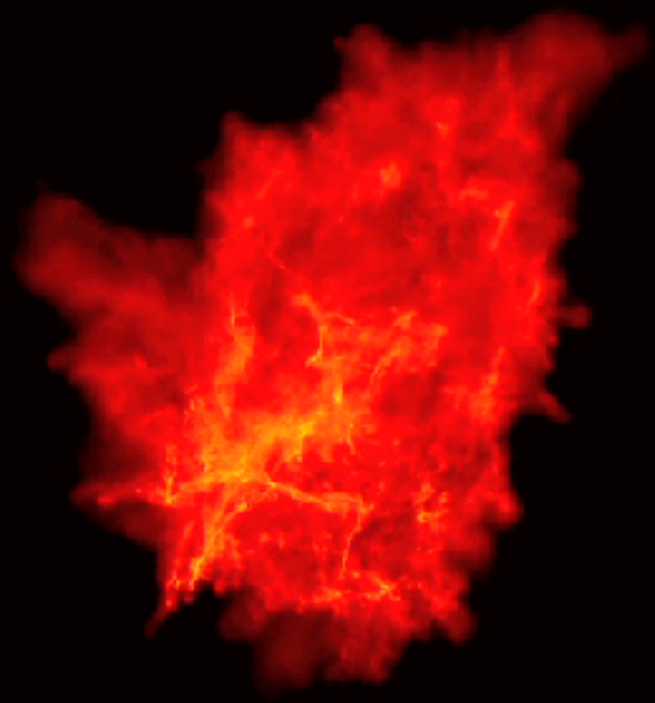




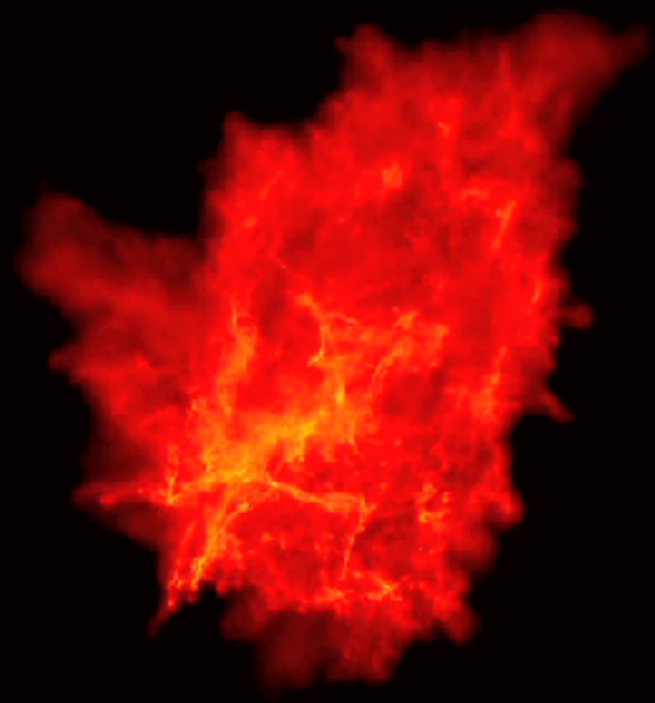
size of the solar system

So what *actually* happens?

Star-forming cloud:

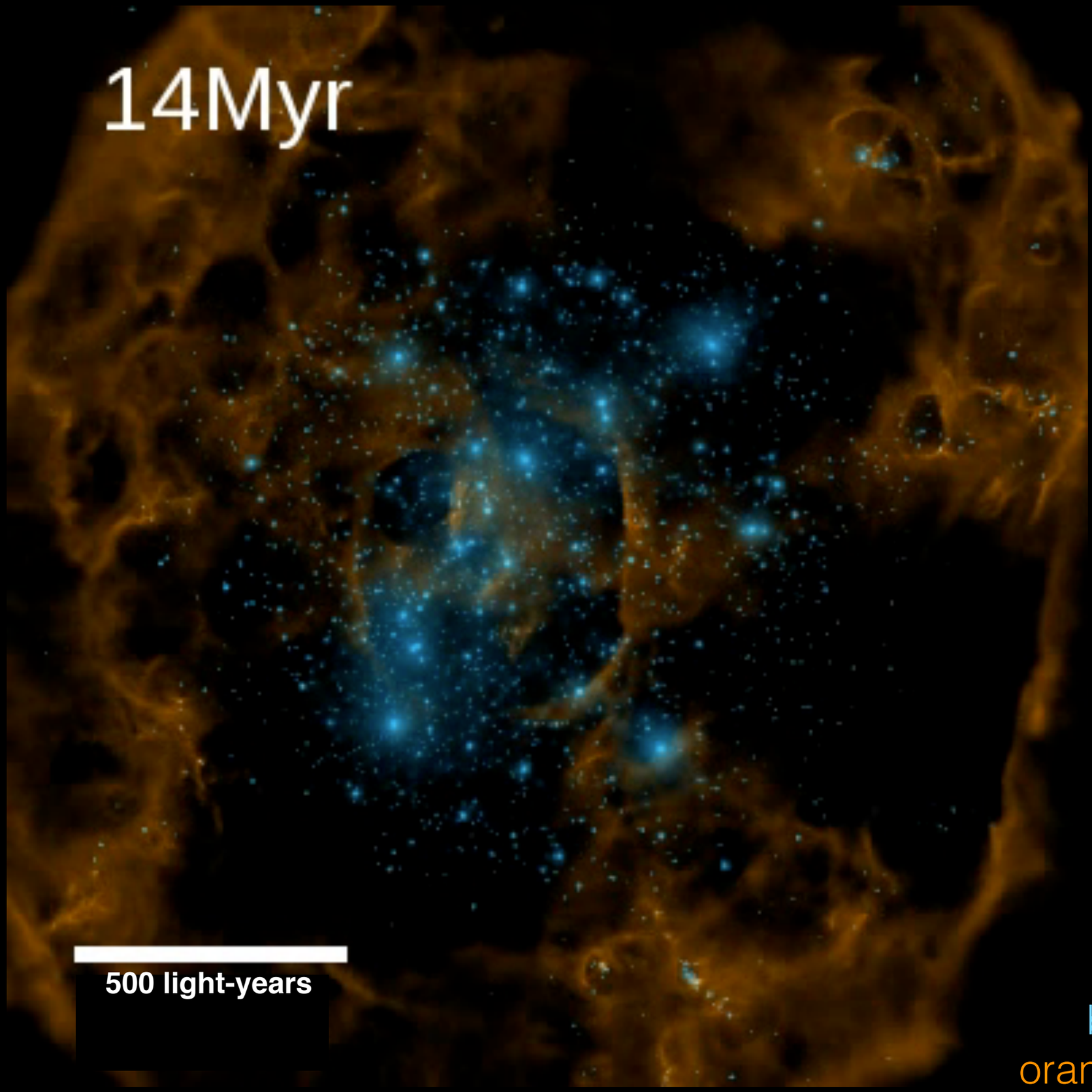


If stars were passive
(wrong)



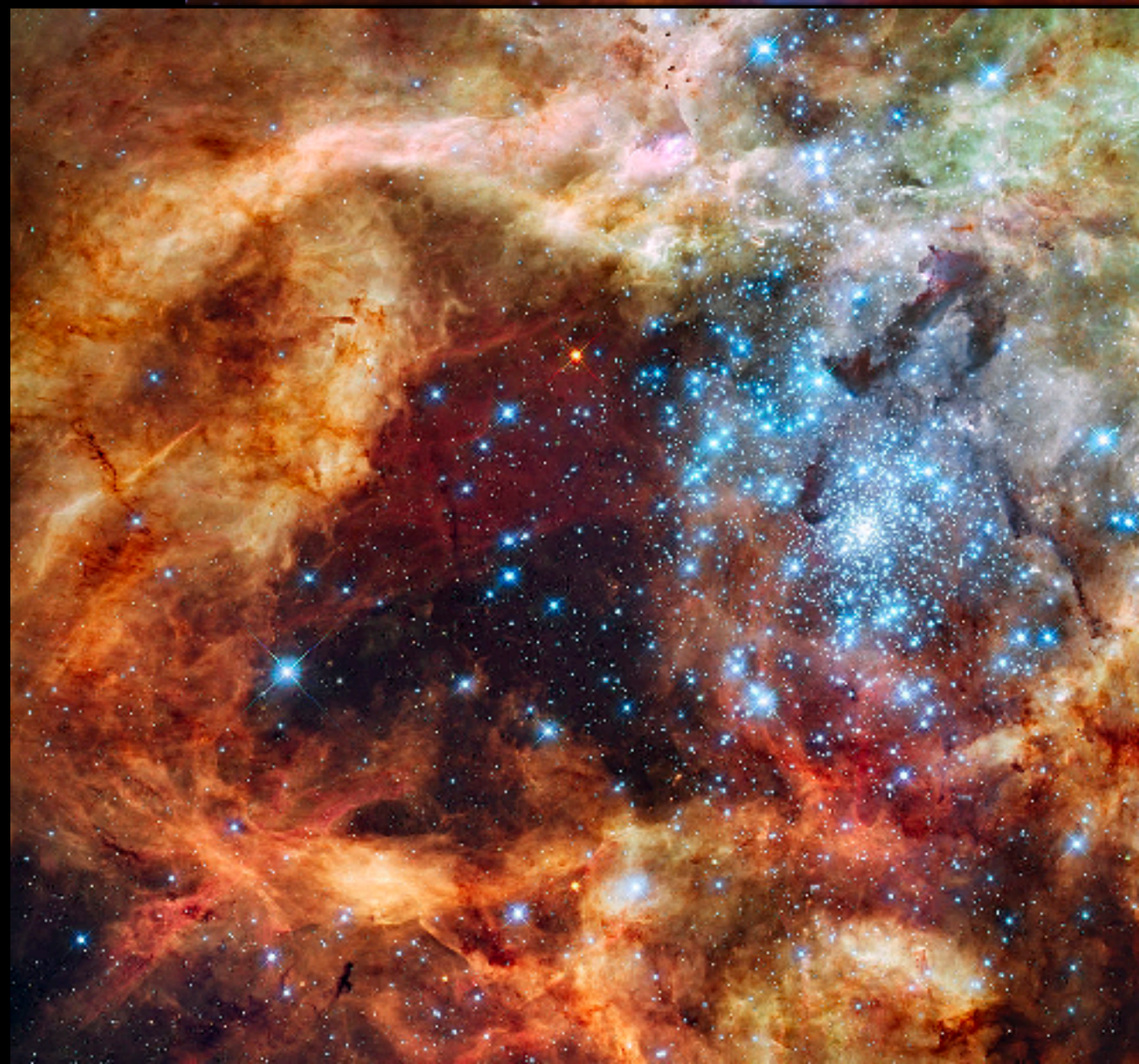
With light & winds from stars
(reality)

So what *actually* happens?

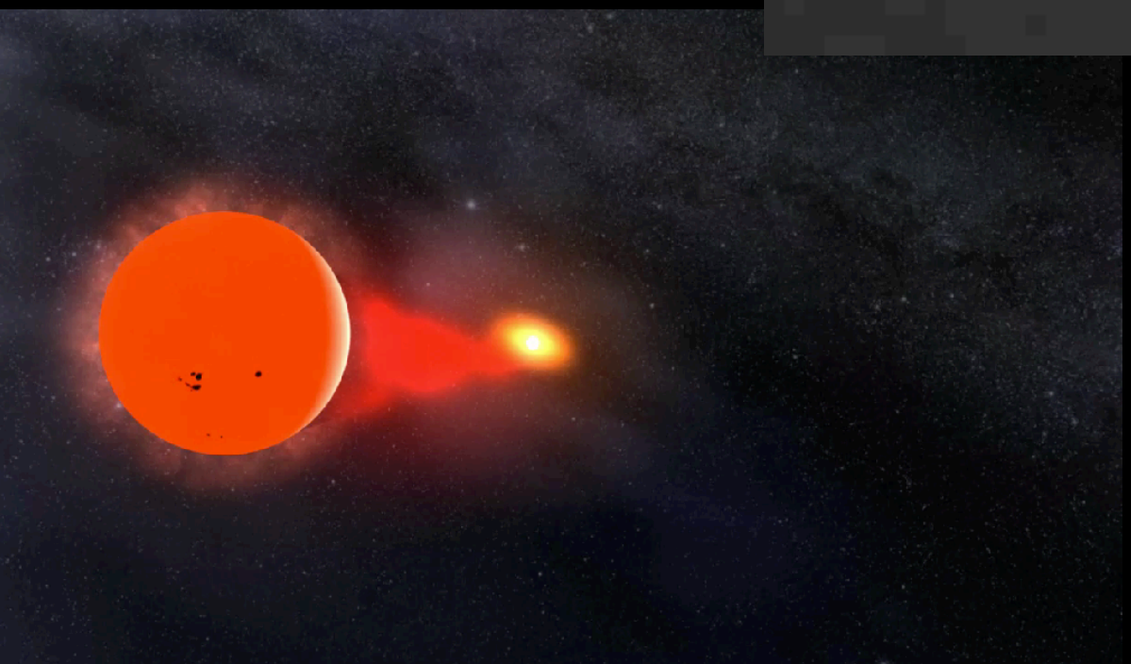


So what *actually* happens?

(real images)



So what *actually* happens?

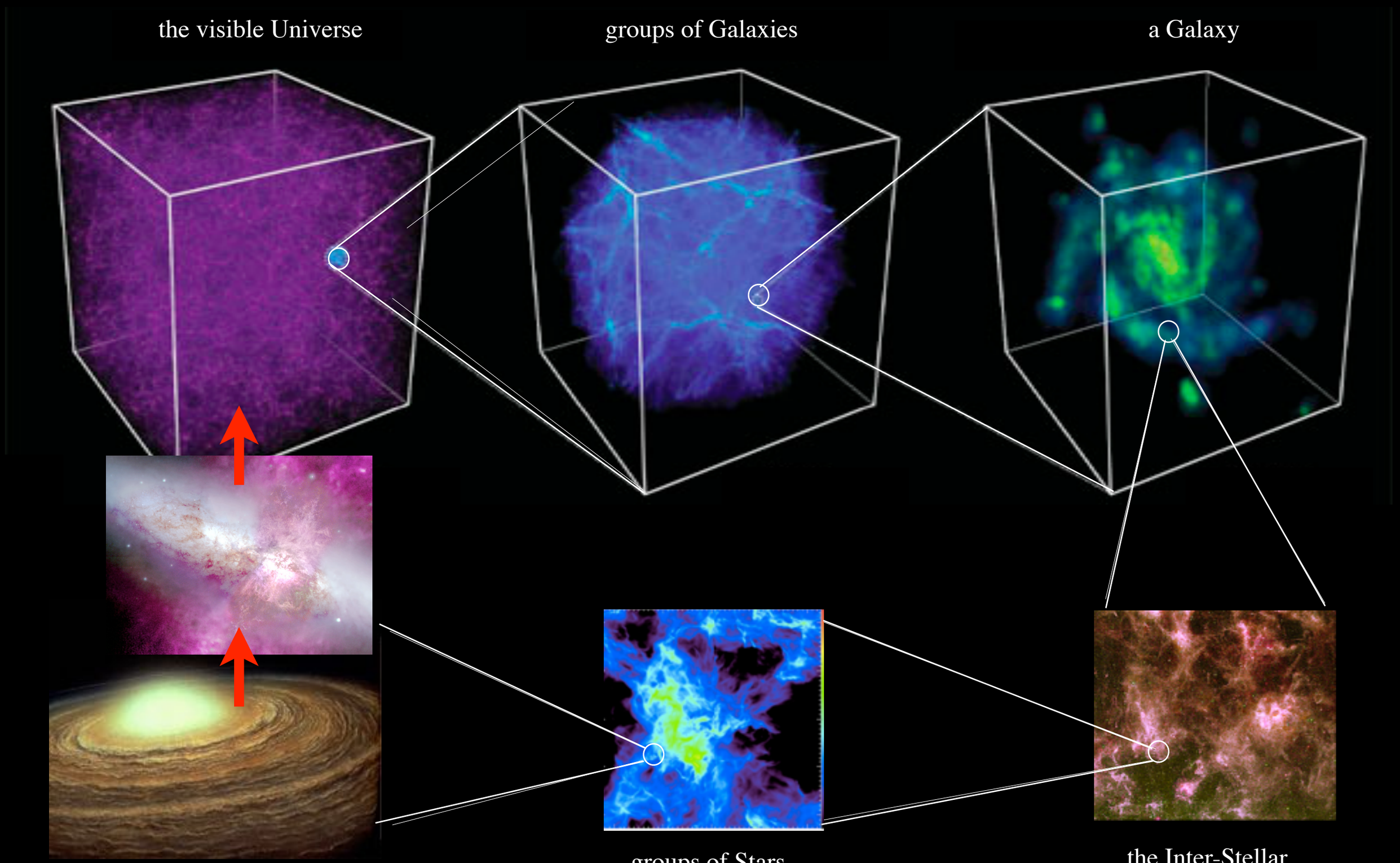


So what *actually* happens?

(10 million supernovae)

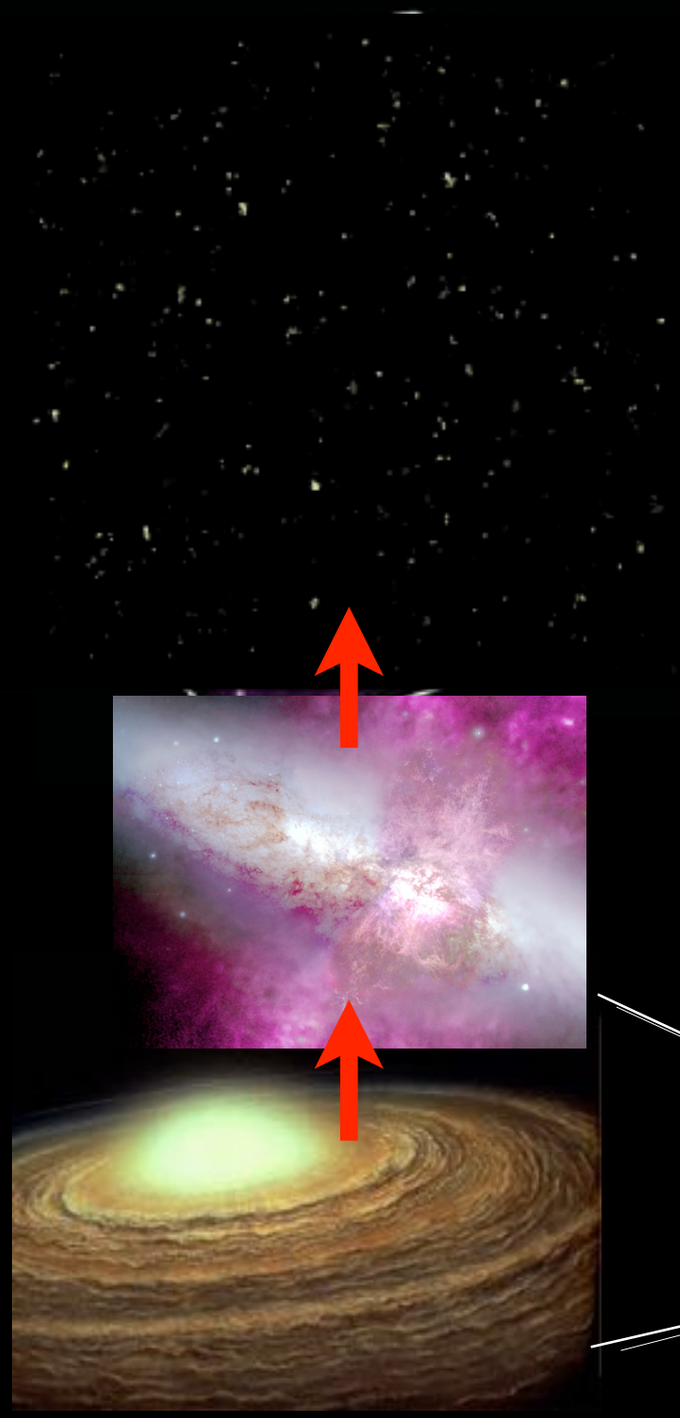
So what *actually* happens?

Nature Hates Theorists…



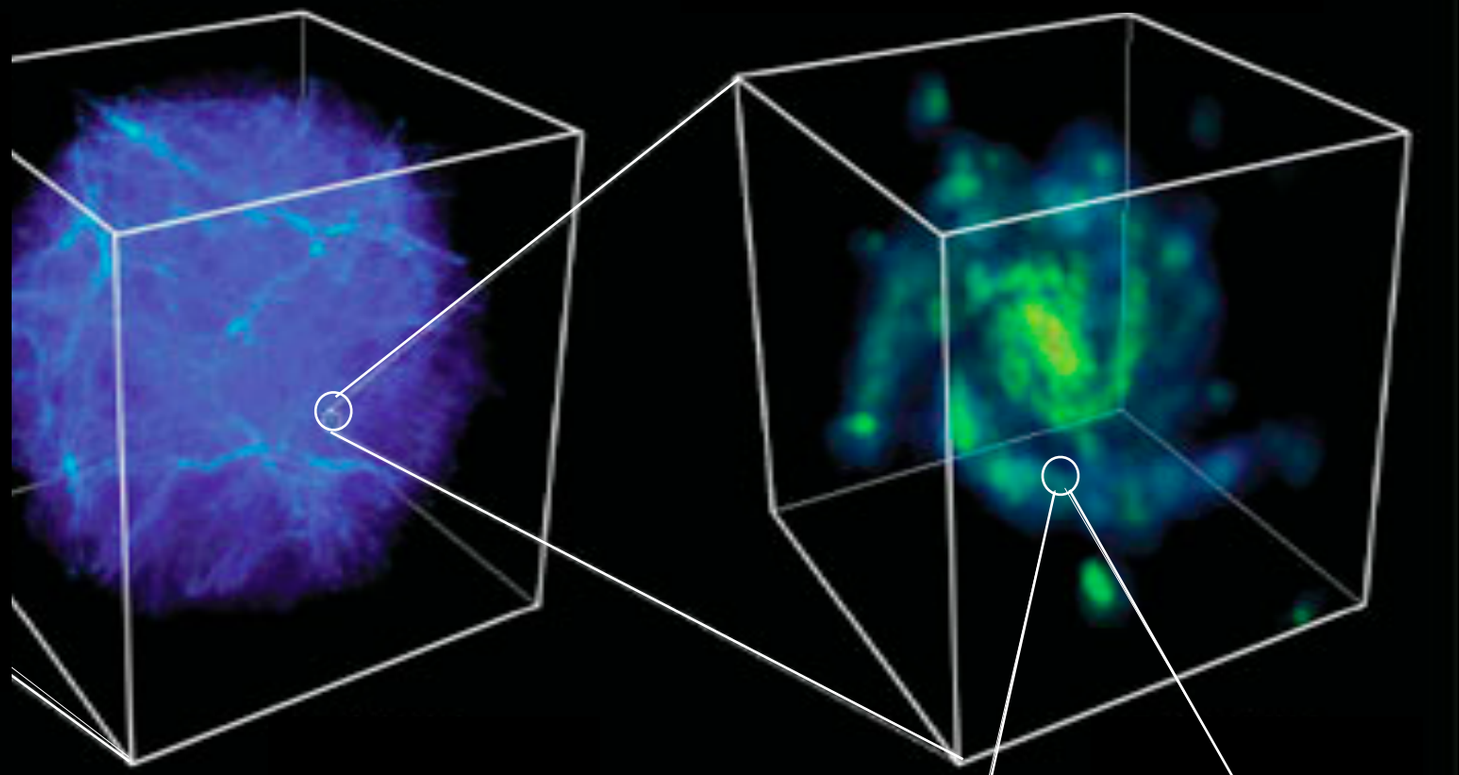
Nature Hates Theorists…

the visible Universe

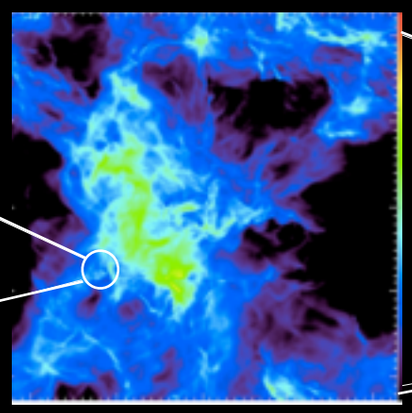


Solar systems

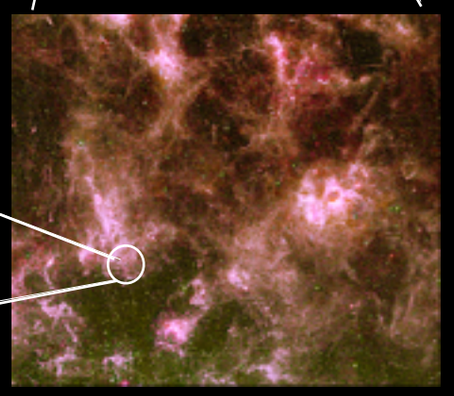
groups of Galaxies



a Galaxy



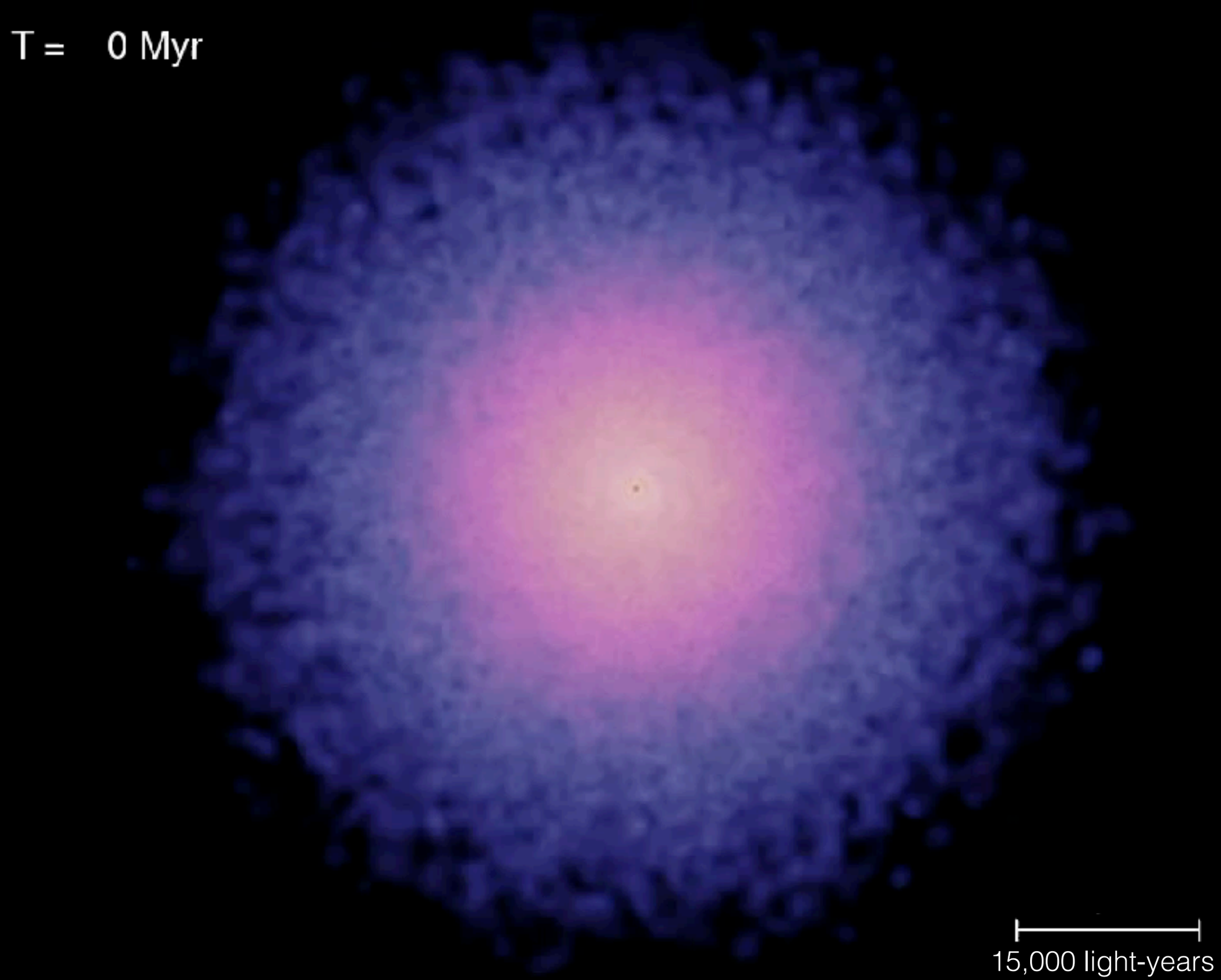
groups of Stars,
gas “clumps” contracting to stars



the Inter-Stellar
Medium (clouds forming stars)

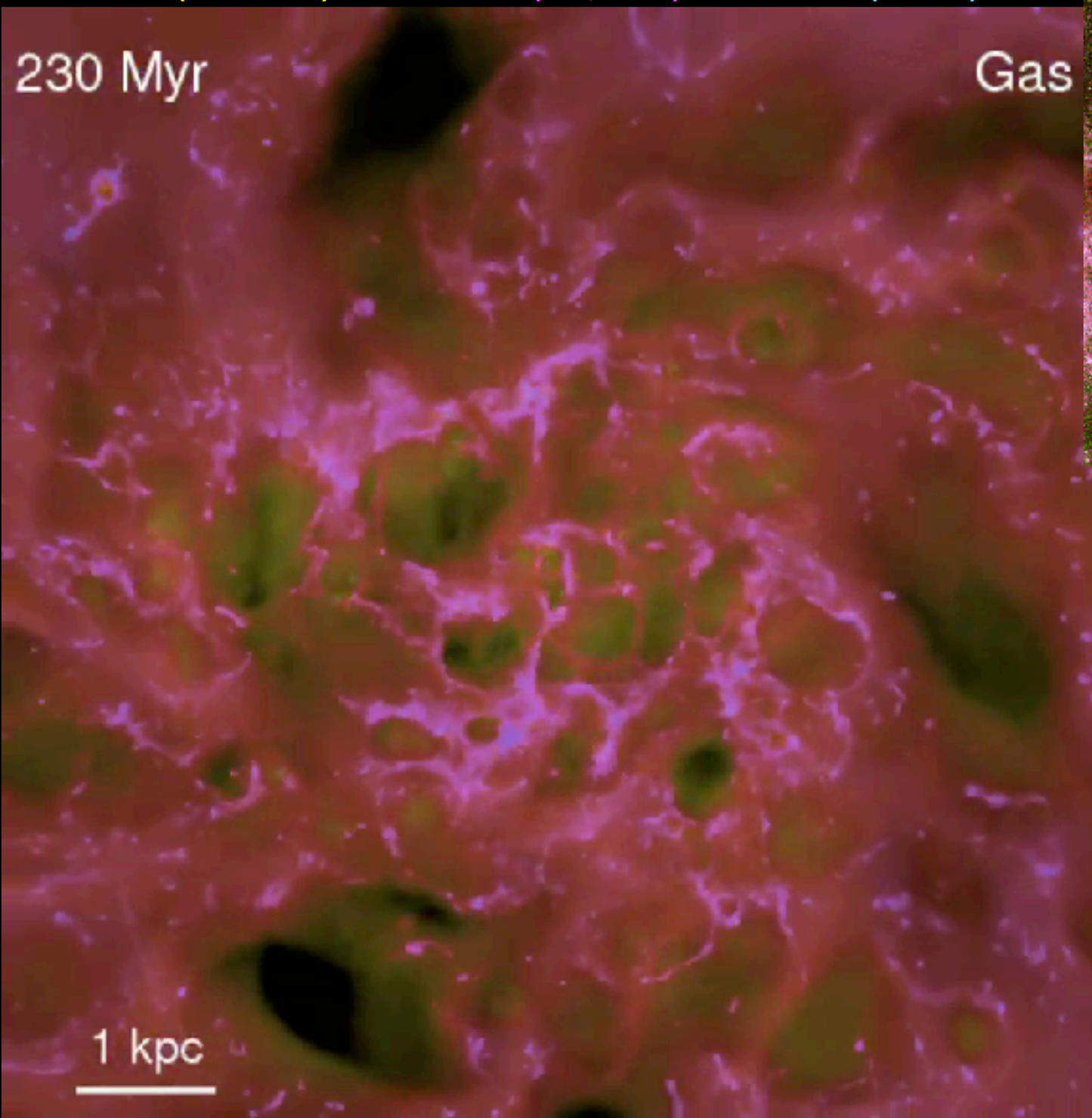
How does it come together?

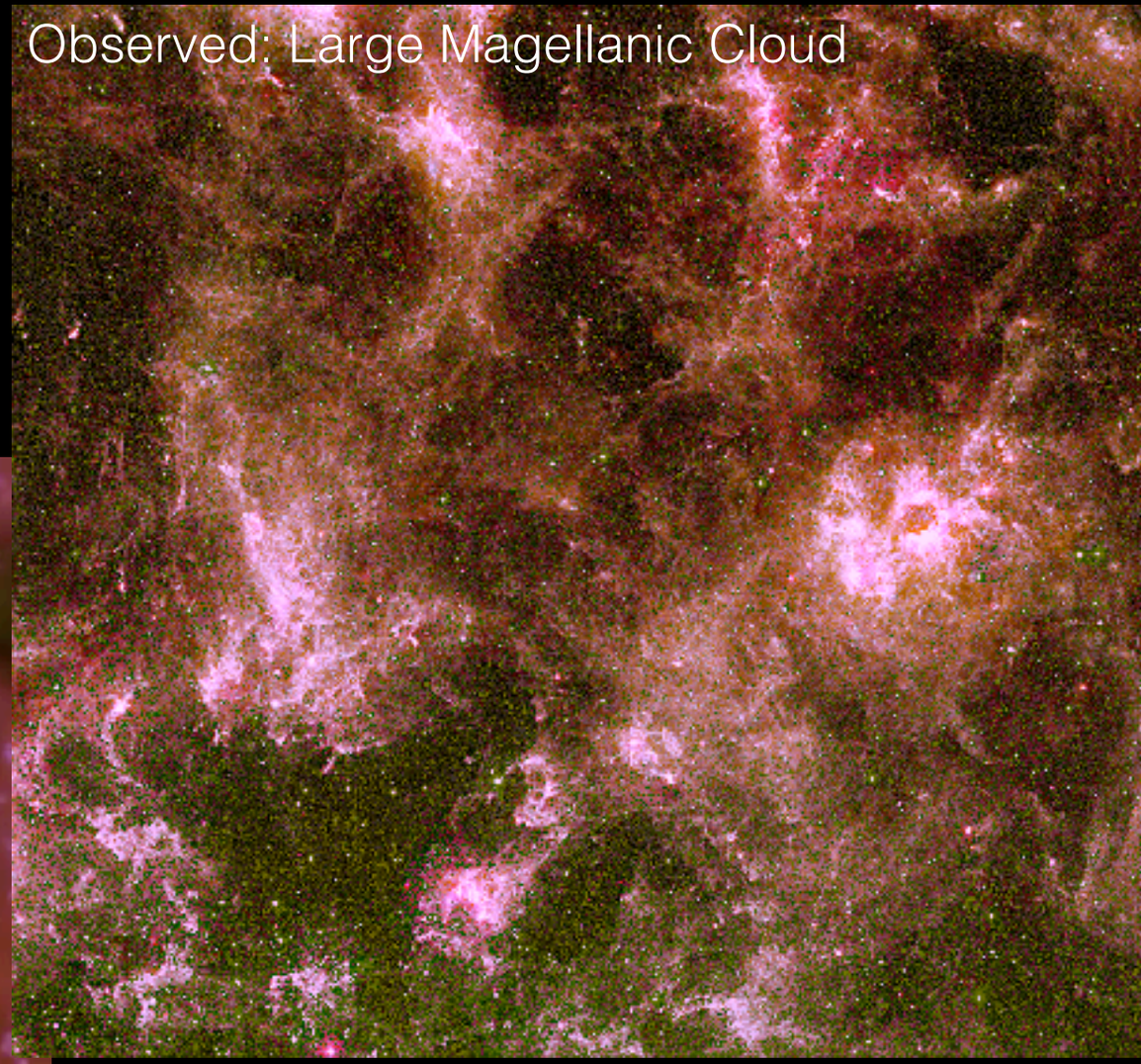
A “Galaxy,” circa 2010…



A “Galaxy,” today…

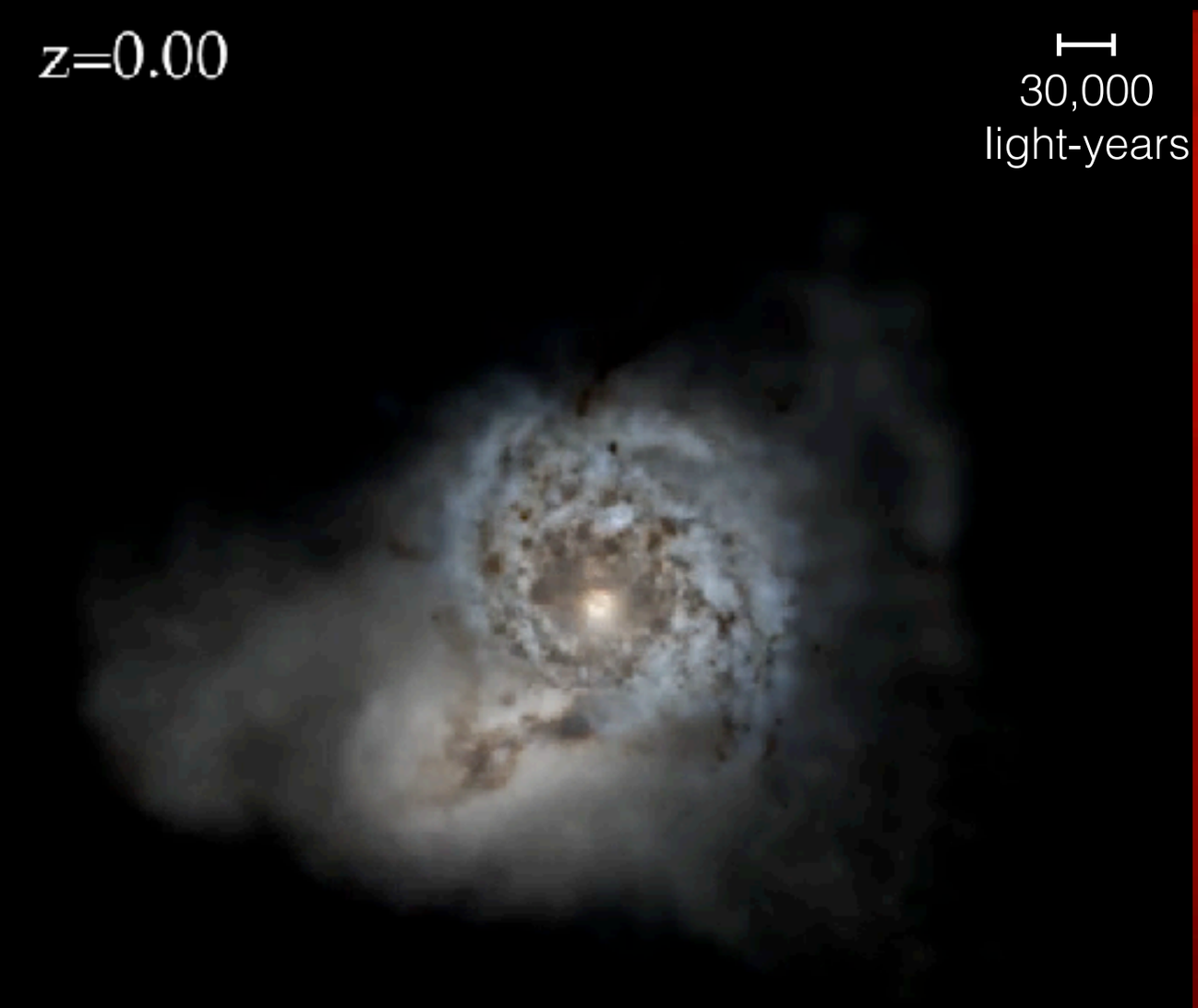
Yellow: hot (>million K) Pink: warm (~10,000 K) Blue: cold (~100 K)



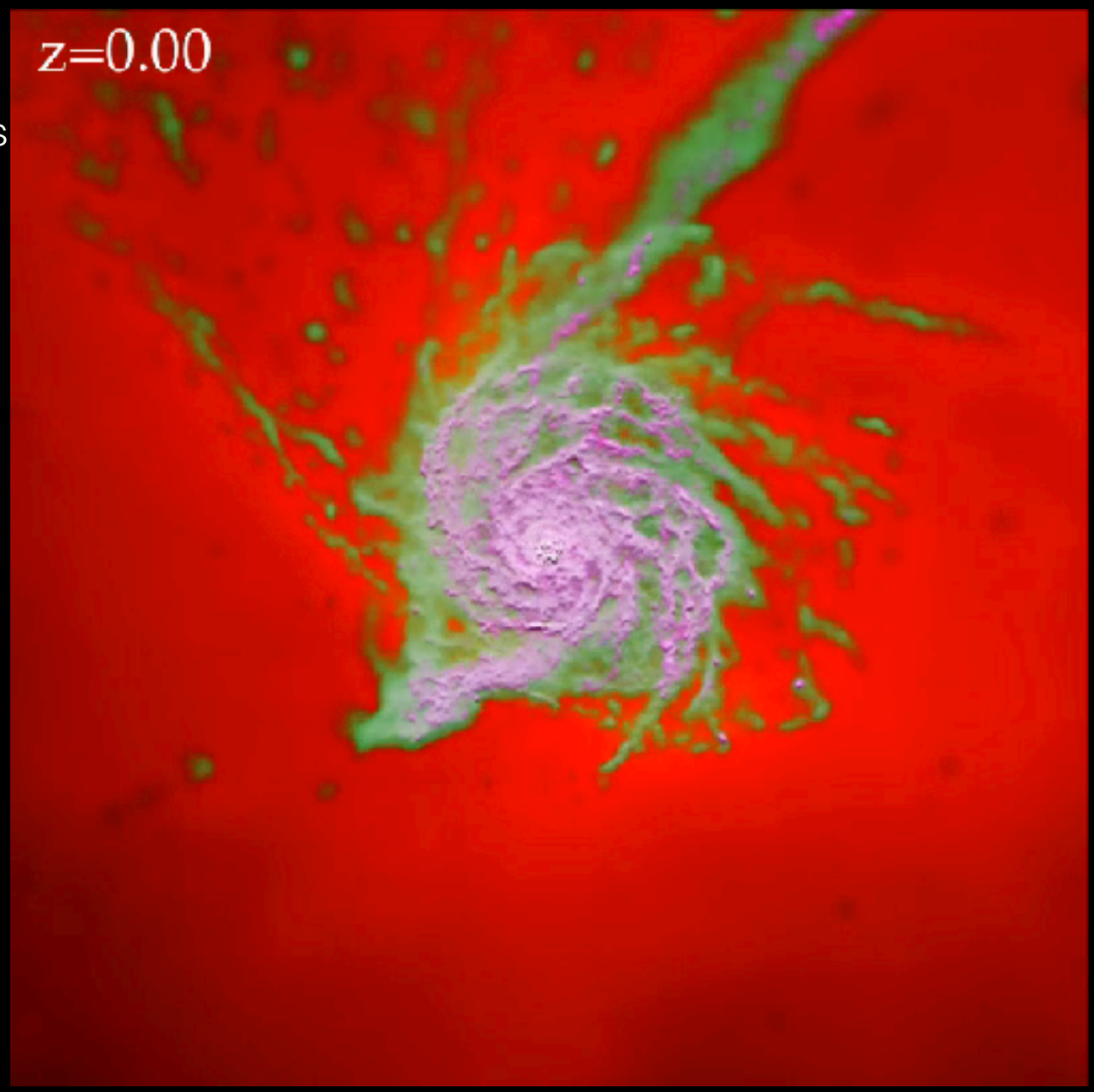


- Gravity & chemistry
- Turbulence (Mach~100)
- Magnetic Fields
- Cosmic rays
- Radiation & winds off stars
- Supernovae

The Life of a Galaxy



30,000
light-years



Stars (Hubble image):

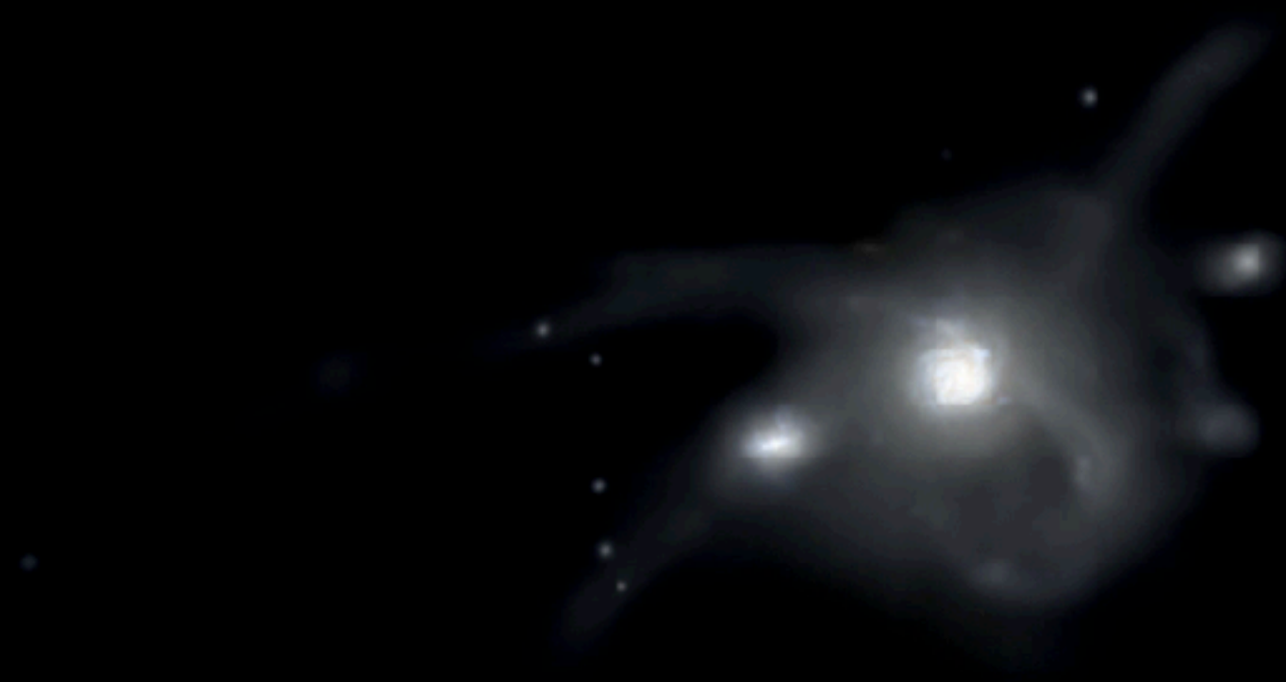
Blue: Young stars

Red: Dust (blocking light)

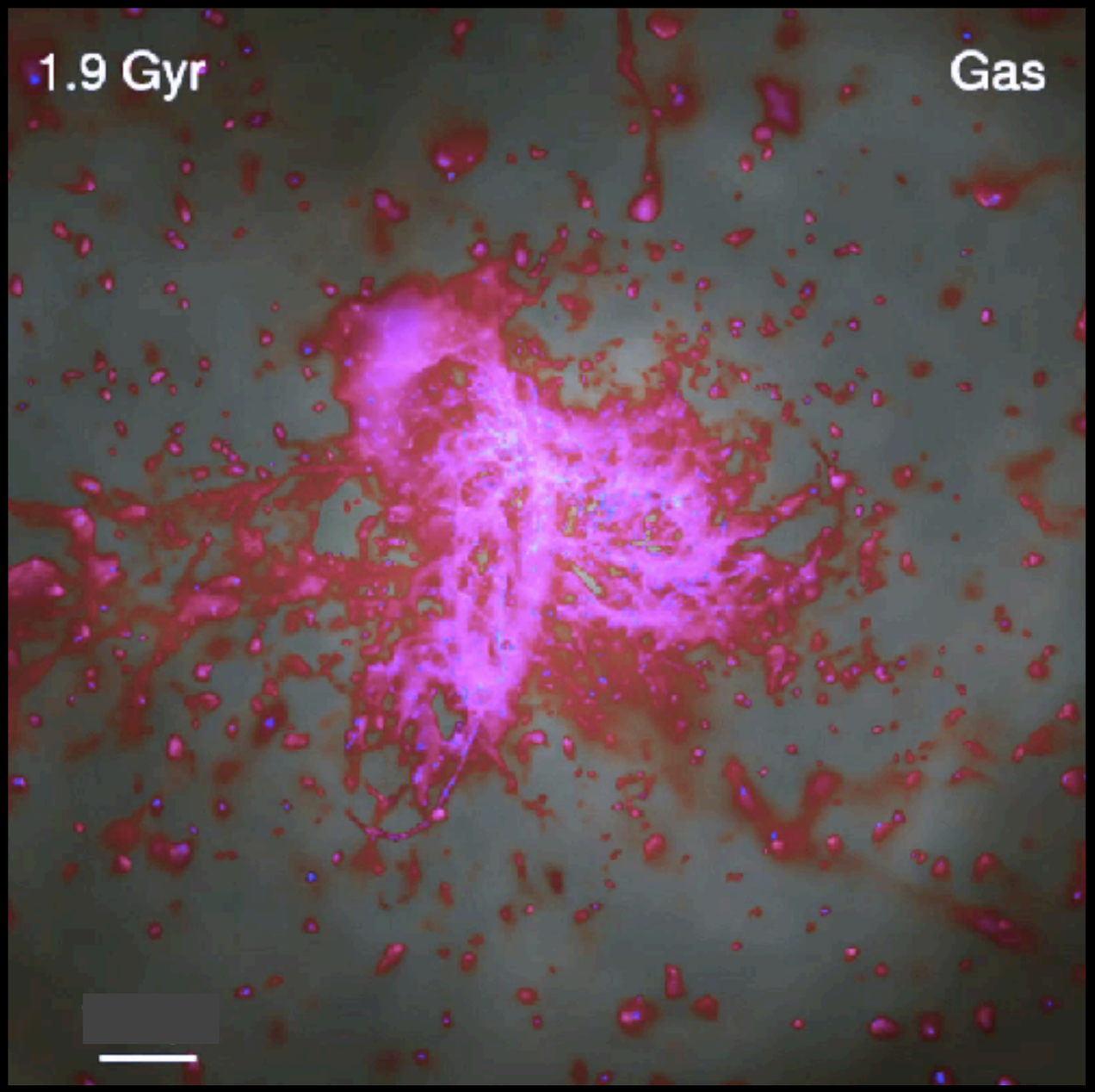
Gas: Magenta: cold (100 K)

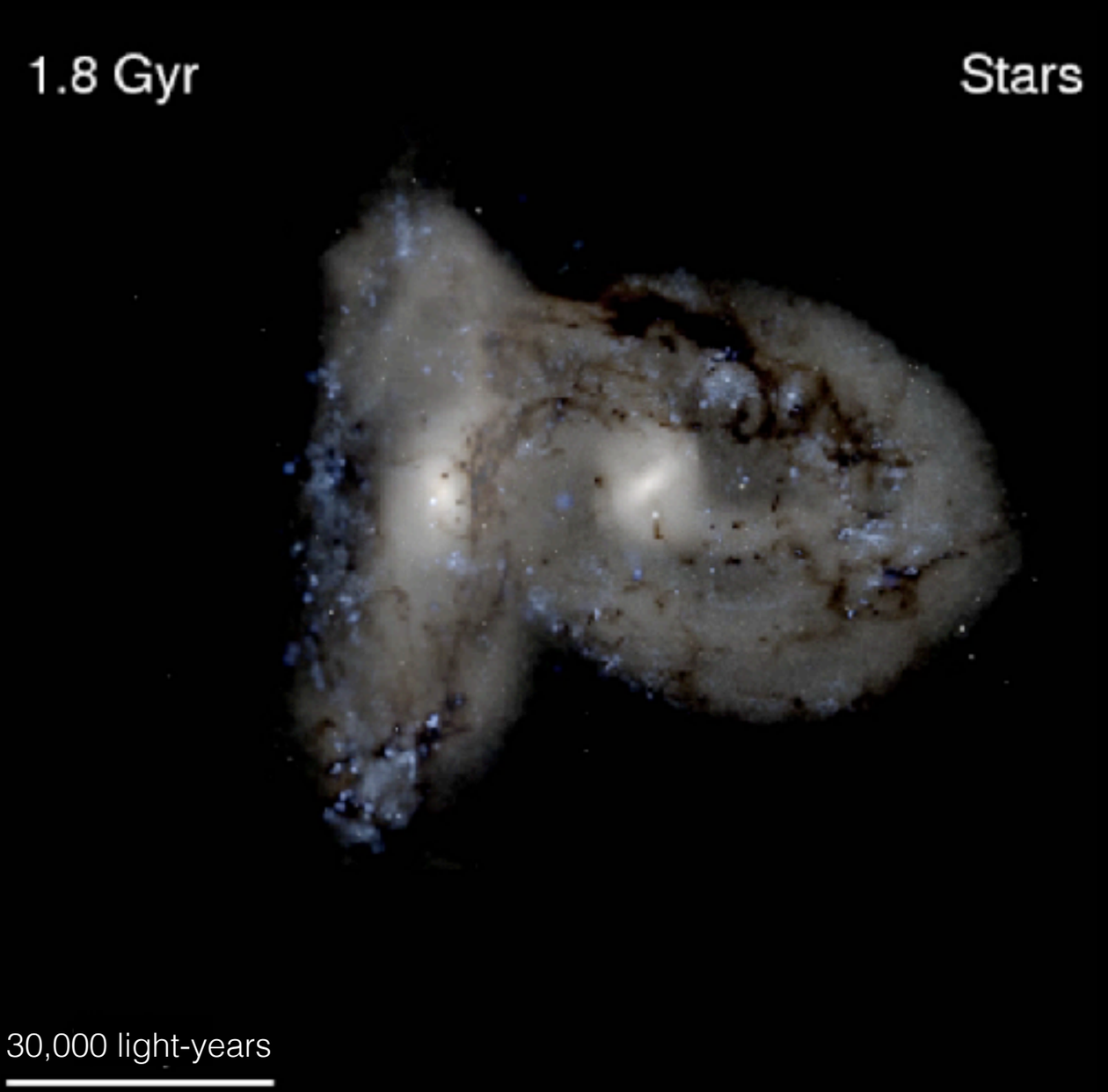
Green: warm (10,000 K)

Red: hot (>1 million K)



When galaxies collide…





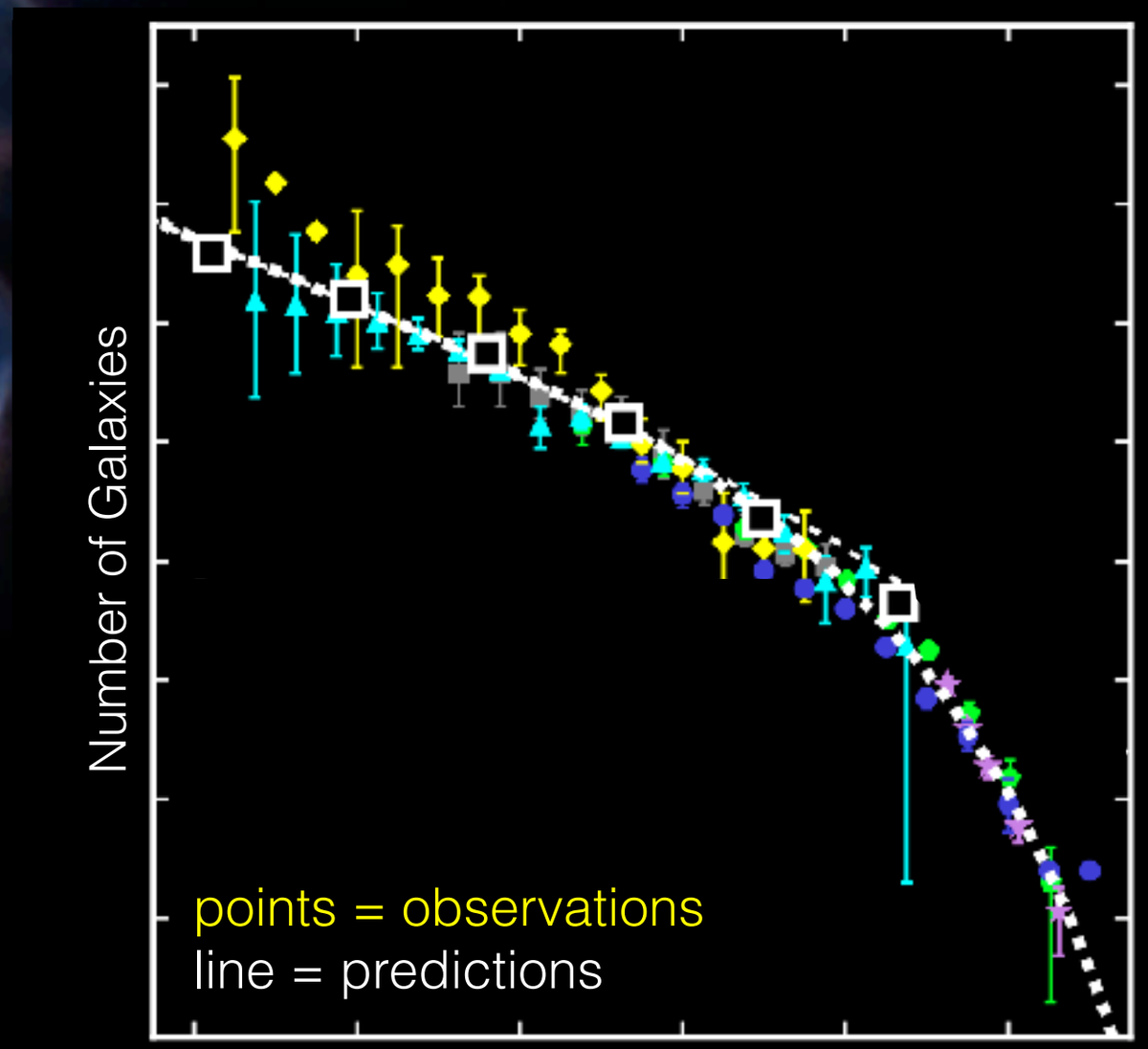
4 Billion Years from now…

The Inter-Galactic Medium

Does It Work?

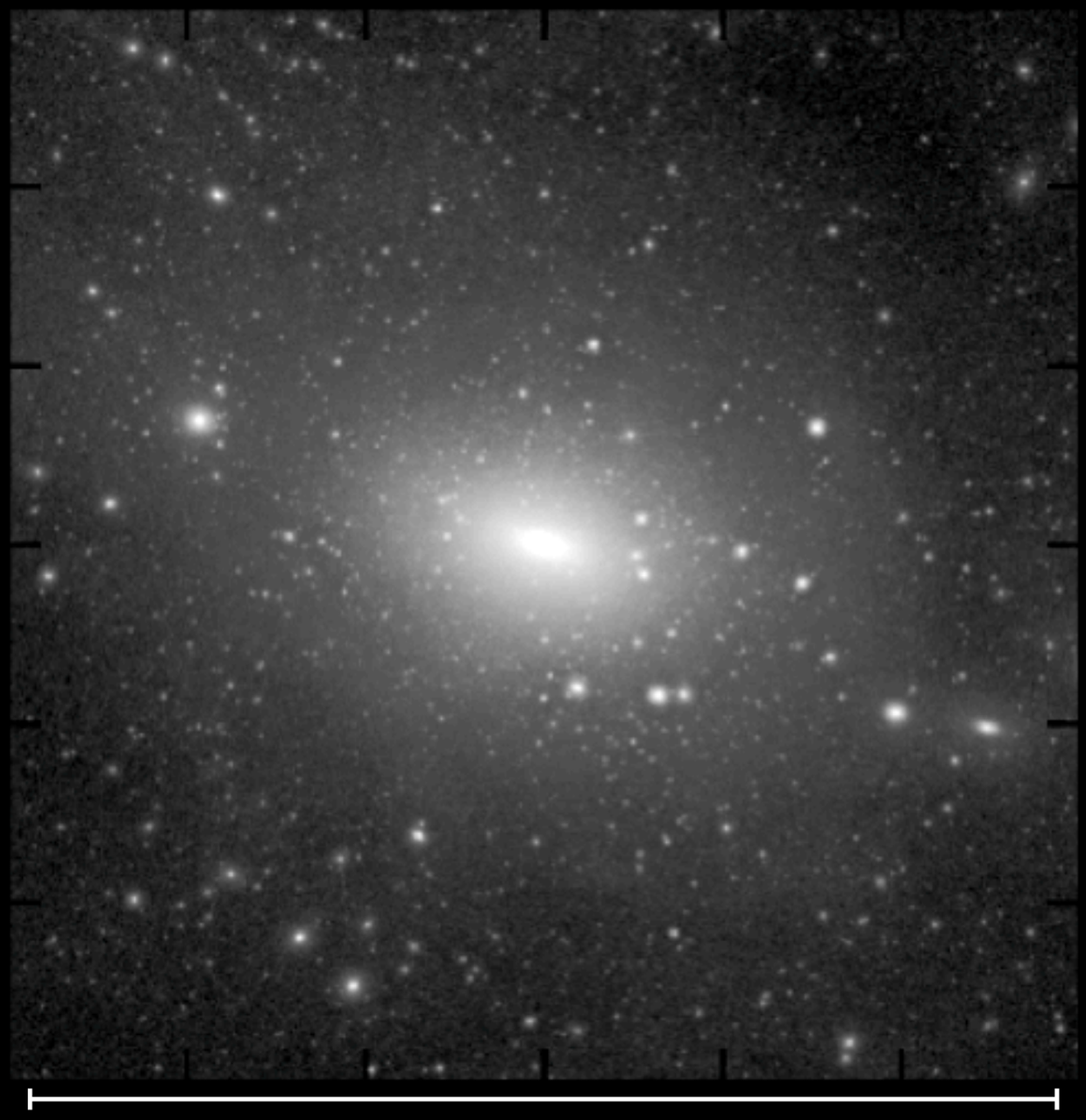
Putting it all together

(Animation: J. Wise)



Stars change our view of the Universe

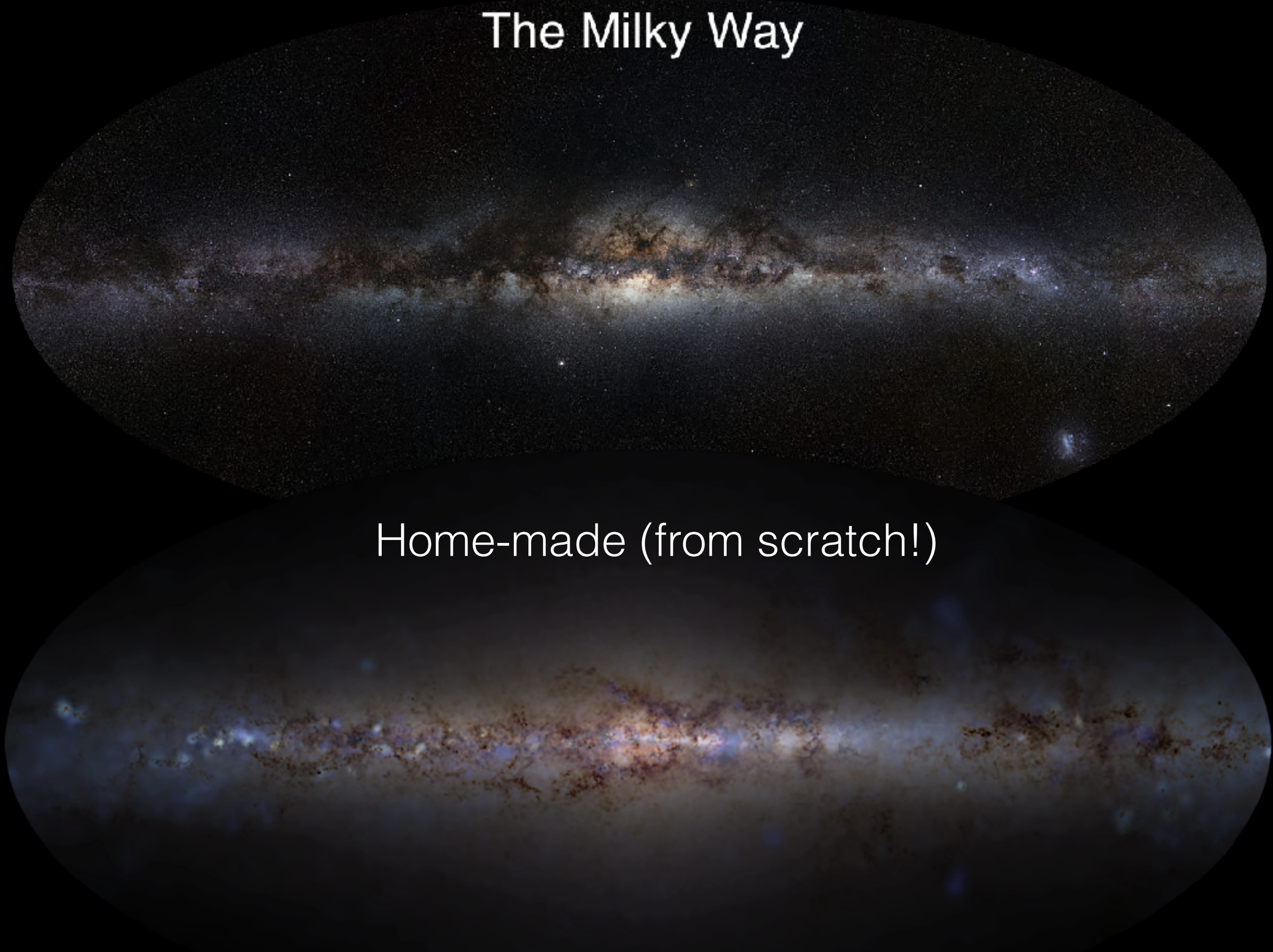
Dark Matter



2 million light-years

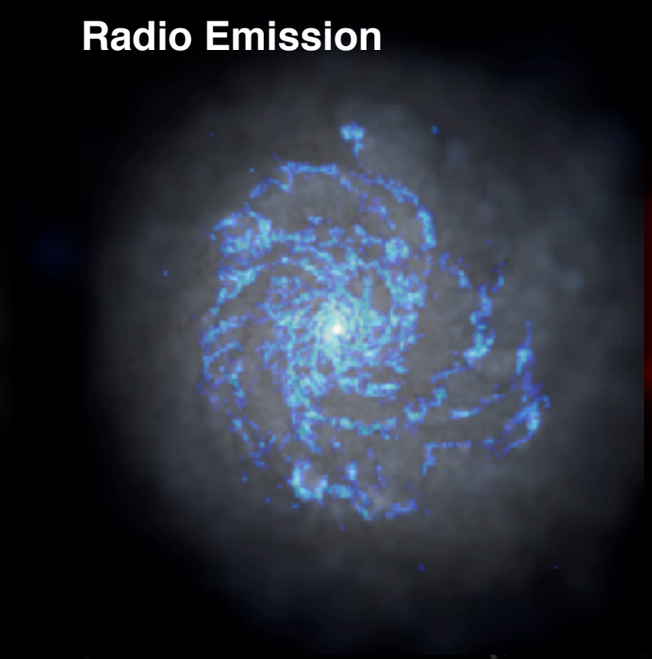
Visible (stars)

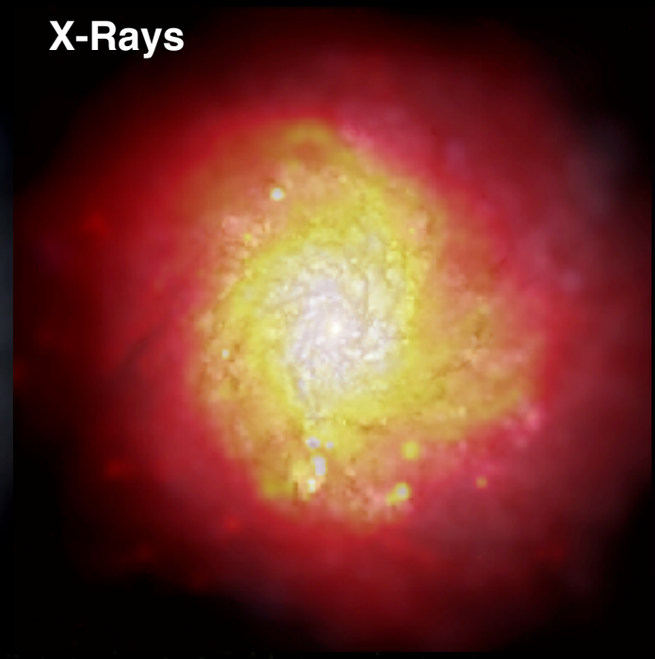
The Milky Way

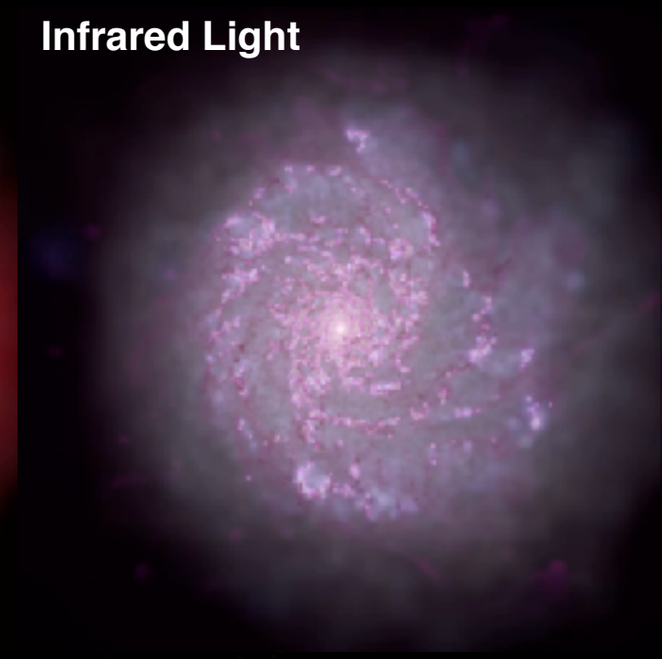


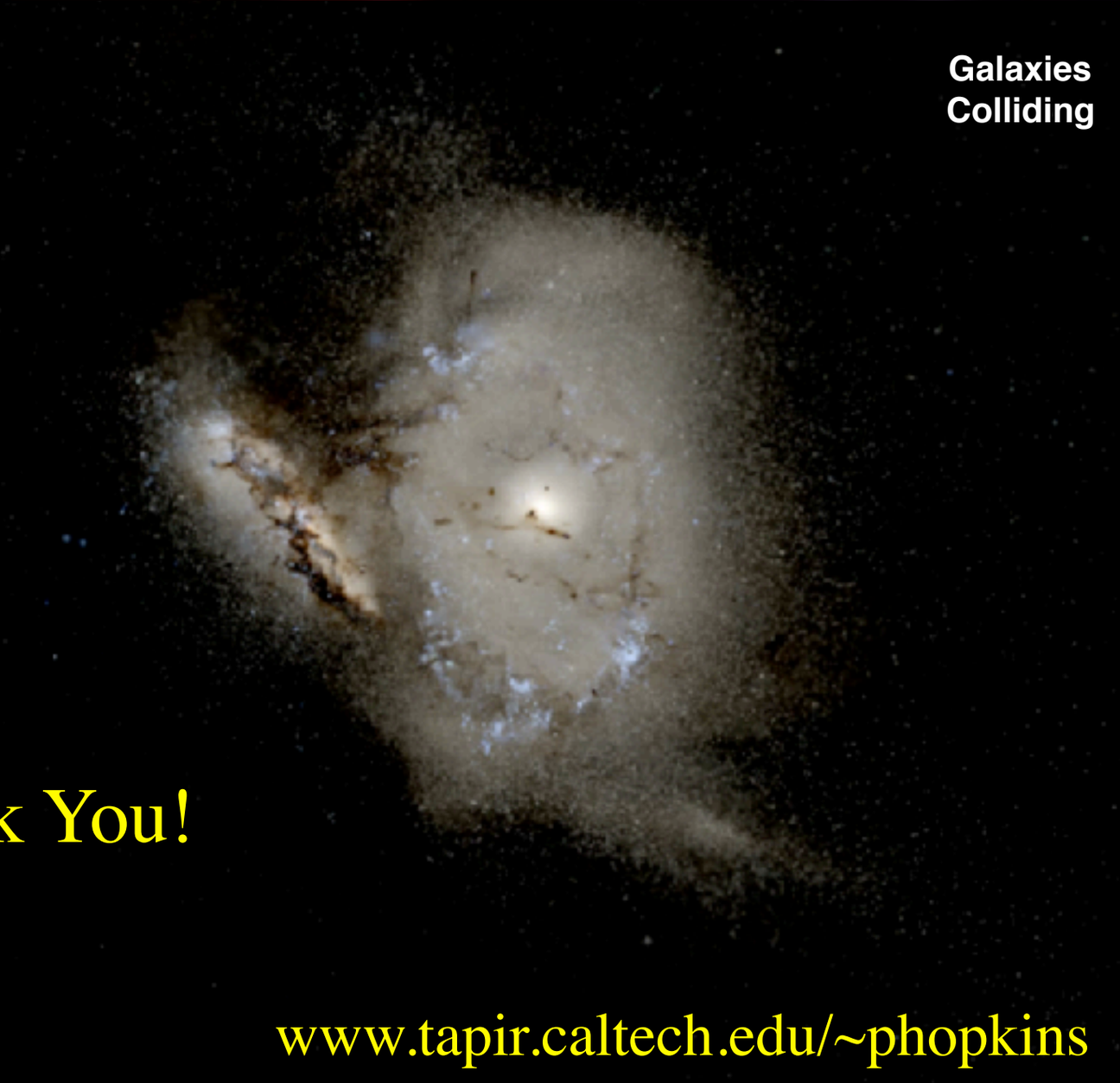
Home-made (from scratch!)

And collisions do important things:









Conclusion:

The Universe is a Violent,
Dynamic, Wonderful Place

Thank You!

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