

# Observational Cosmology

( ObsCos )

Prof. Joaquin Vieira



11 Feb2022




# Big questions (for me):

How did the **universe** begin ?

When did the first **galaxies** form ?

How does the universe **evolve** over time ?

Is there **life** out there ?



I grew up in rural central CA.

**UCLA**

BS Astrophysics 2002

THE UNIVERSITY OF  
**CHICAGO**

PhD Physics 2009

**Caltech**

postdoc 2009—2013

**I ILLINOIS** faculty 2013 —

Astronomy + Physics + NCSA



observing the beginning of the universe from  
the bottom of the world



J as a graduate student at the South Pole in 2006.



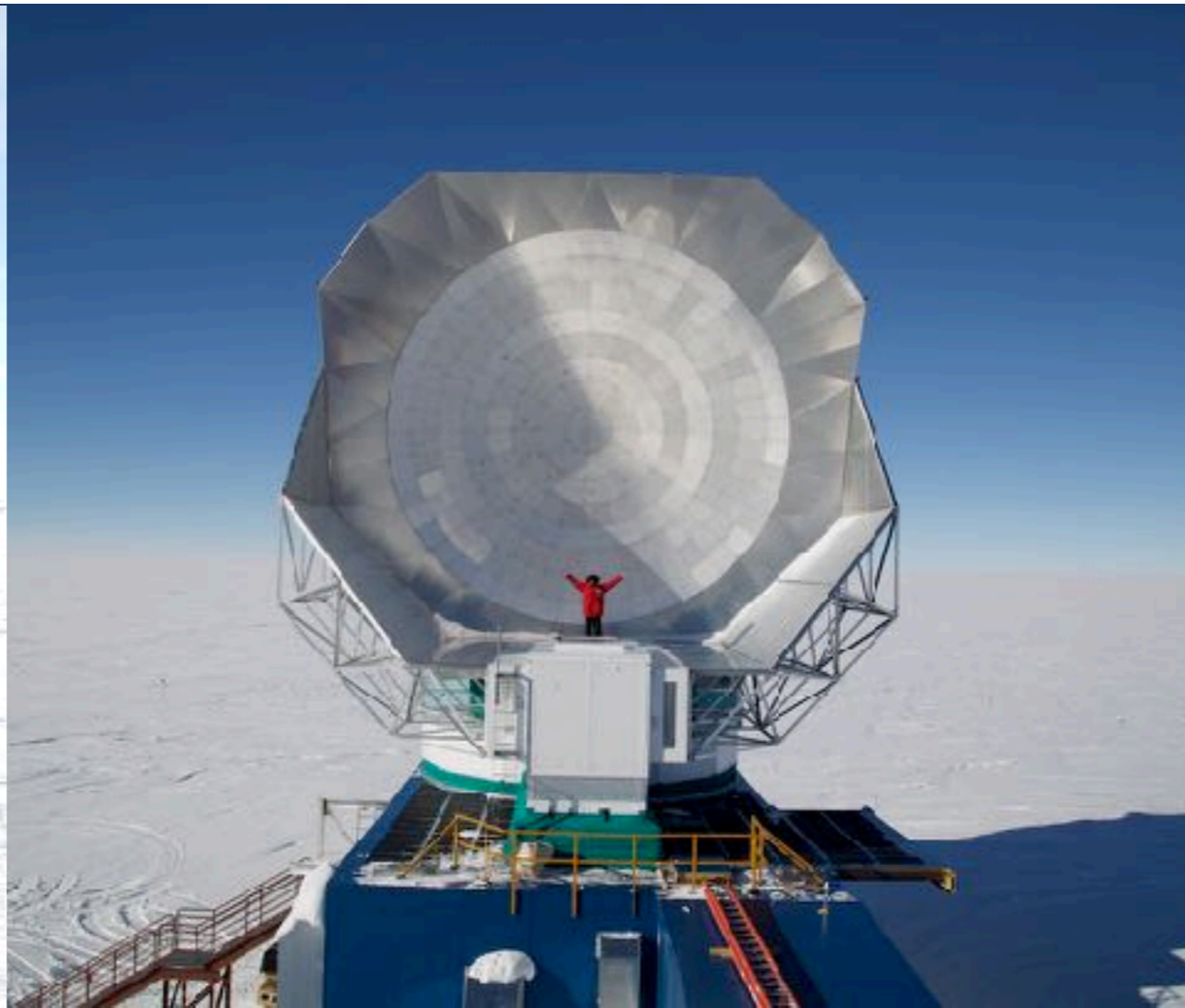
J standing in the South Pole Telescope



Older Prof. J c. 2017



J as a graduate student at the South Pole in 2006.



Dr. Andrew Nadolski  
Astronomy PhD  
U. Illinois 2020



Older Prof. J  
c. 2017



# The 10-meter South Pole Telescope



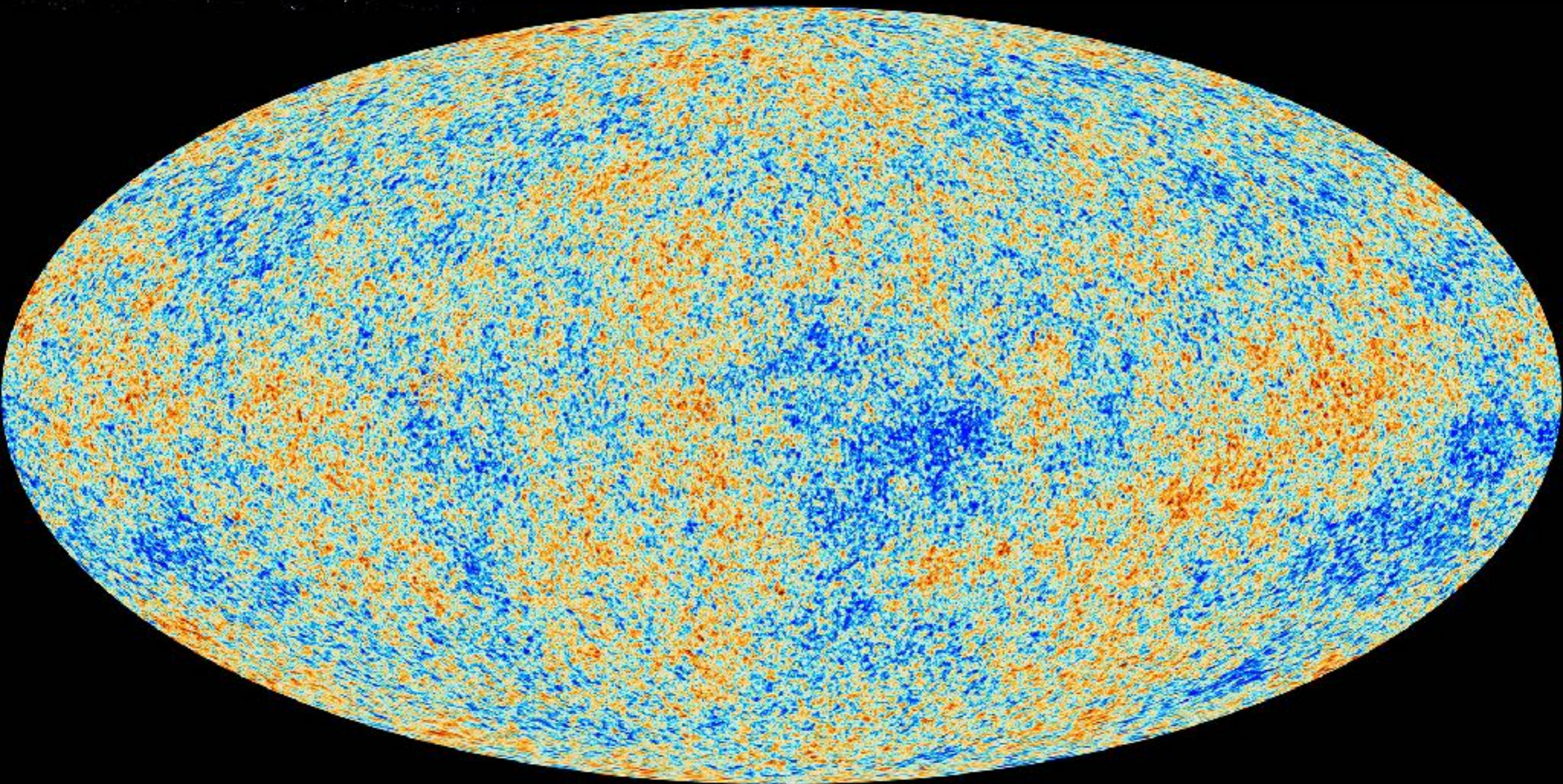
**I** ILLINOIS  
graduate student  
Andrew Nadolski  
for scale



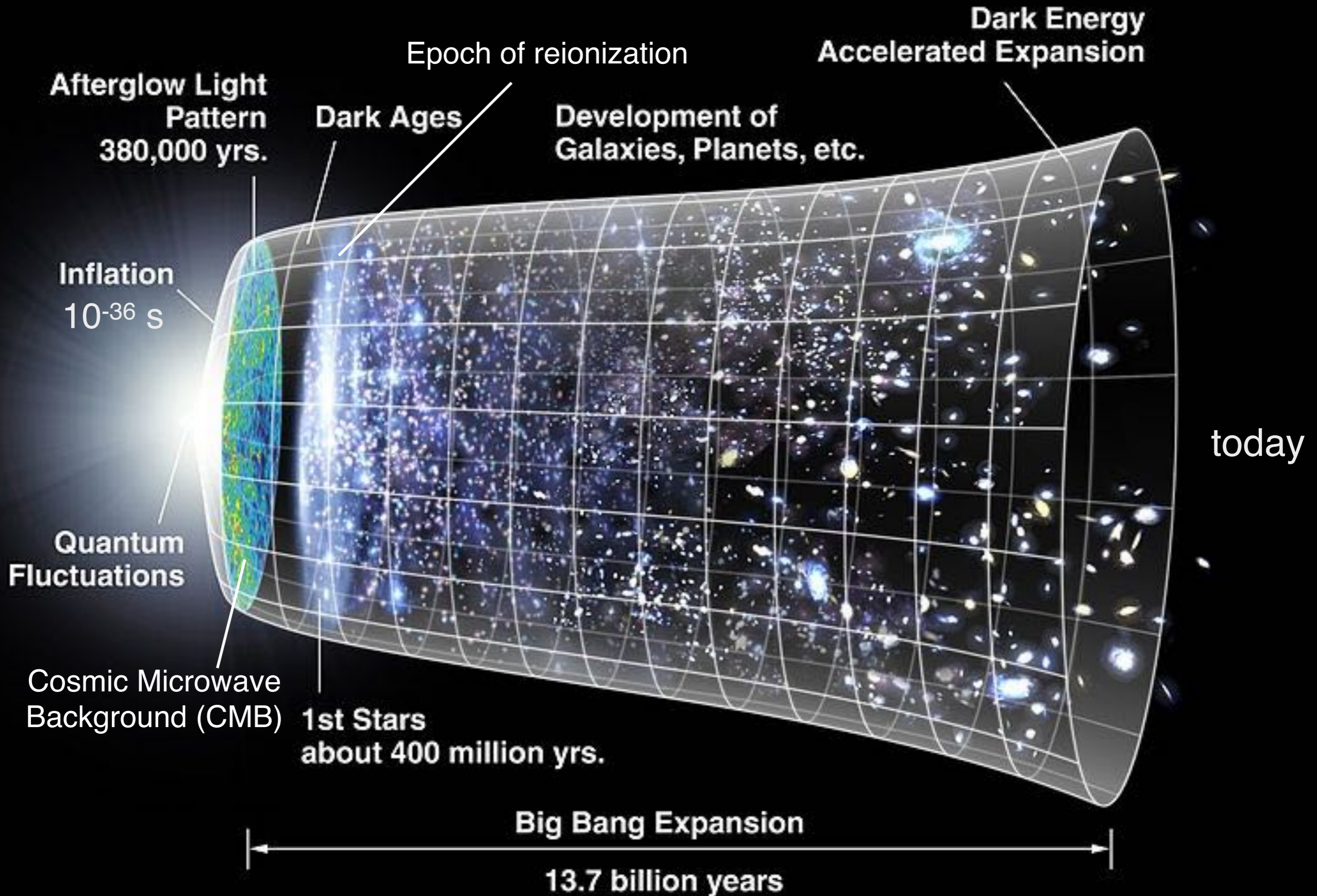


# ESA *Planck* Satellite

The Cosmic Microwave Background (CMB)



# Brief History of the Universe



1 day old



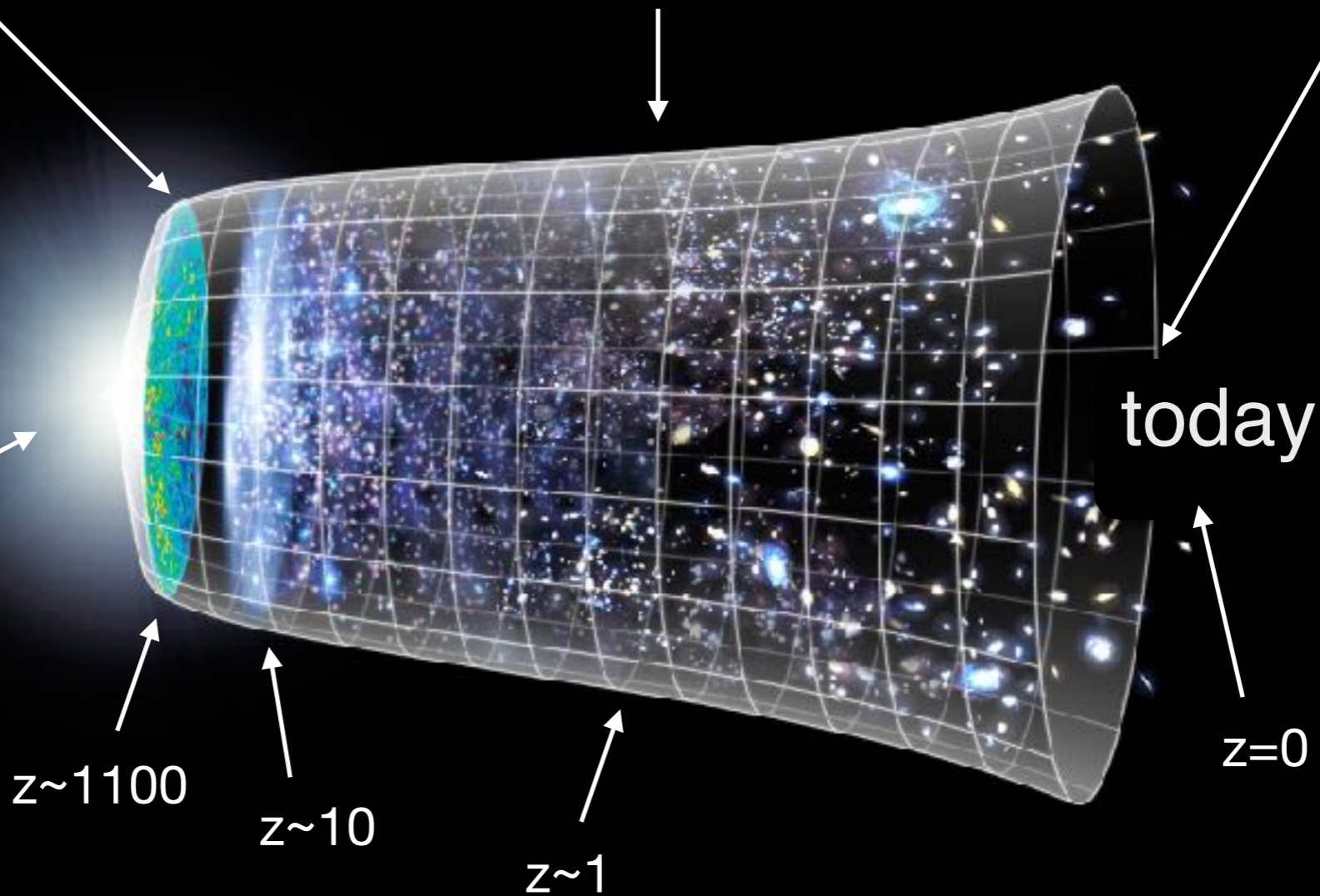
middle age



80 yrs old



inception



**SPTpol**

***Planck***

1°



# SPTpol

500 deg<sup>2</sup> survey at 150 GHz with arcminute resolution

full moon for scale



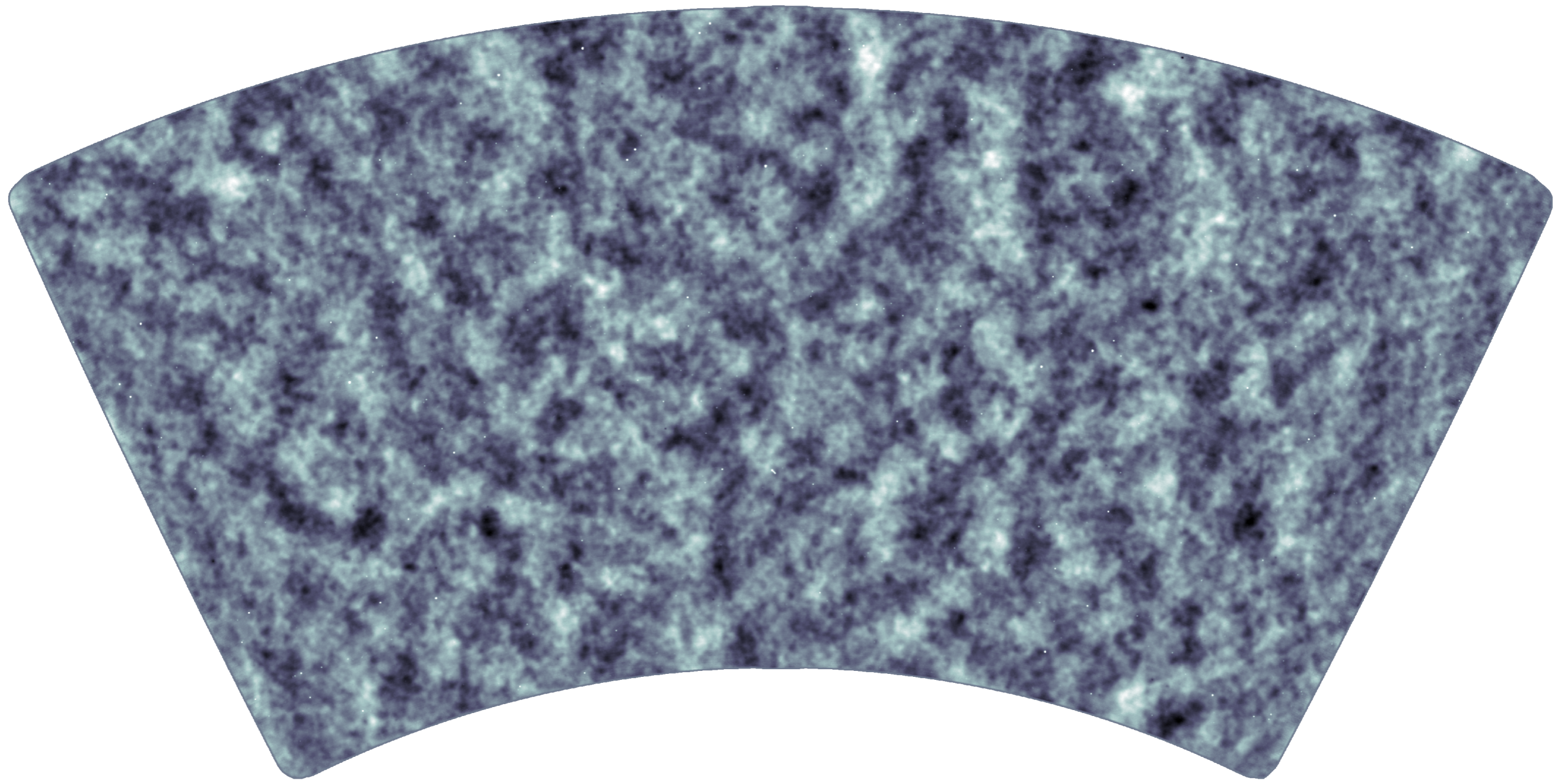
**SPTpol** —> 2nd gen. camera and survey

x3 as deep as SPT-SZ

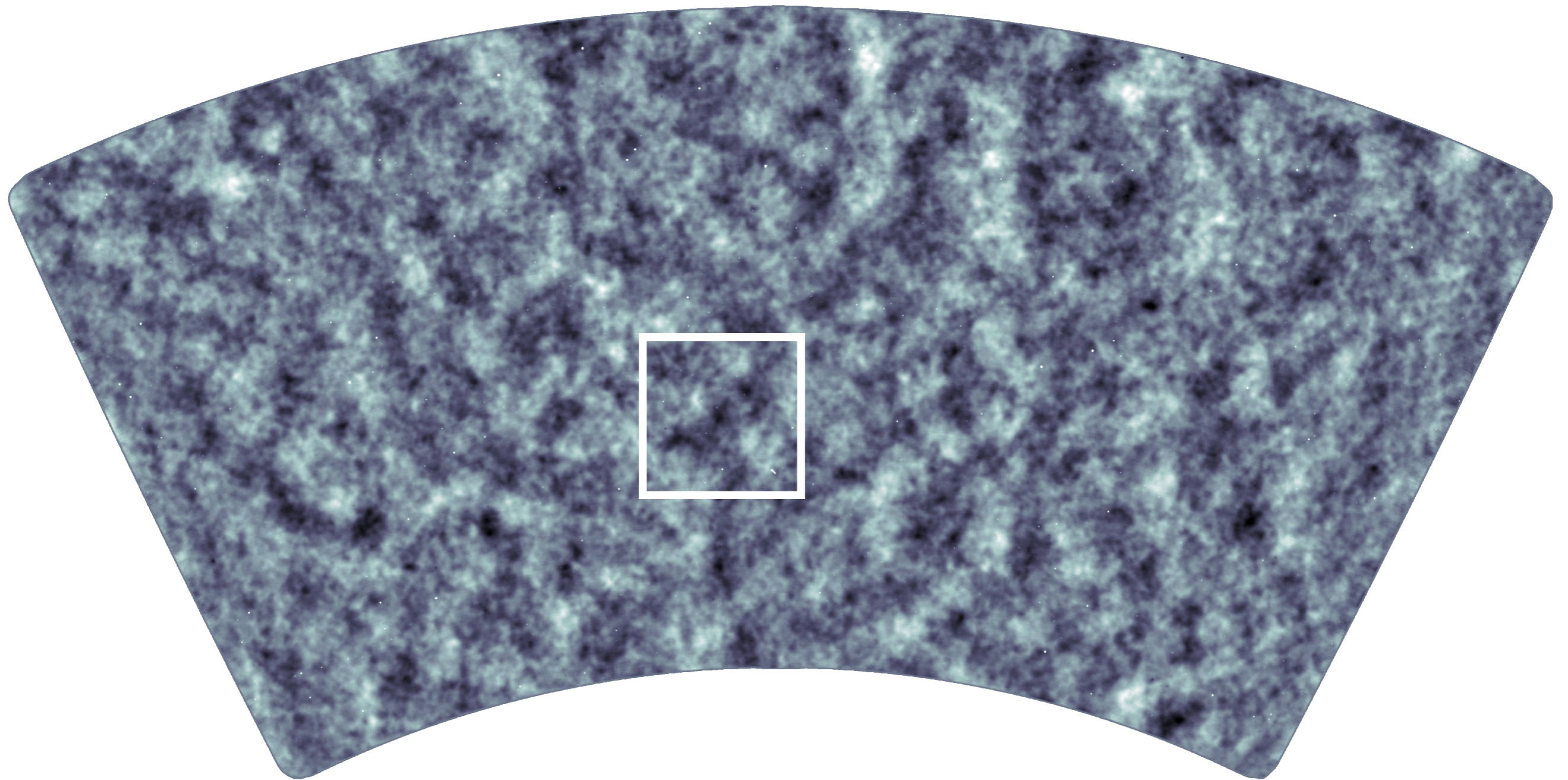
**SPT-3G** —> 3rd gen. camera and survey

x3 the area

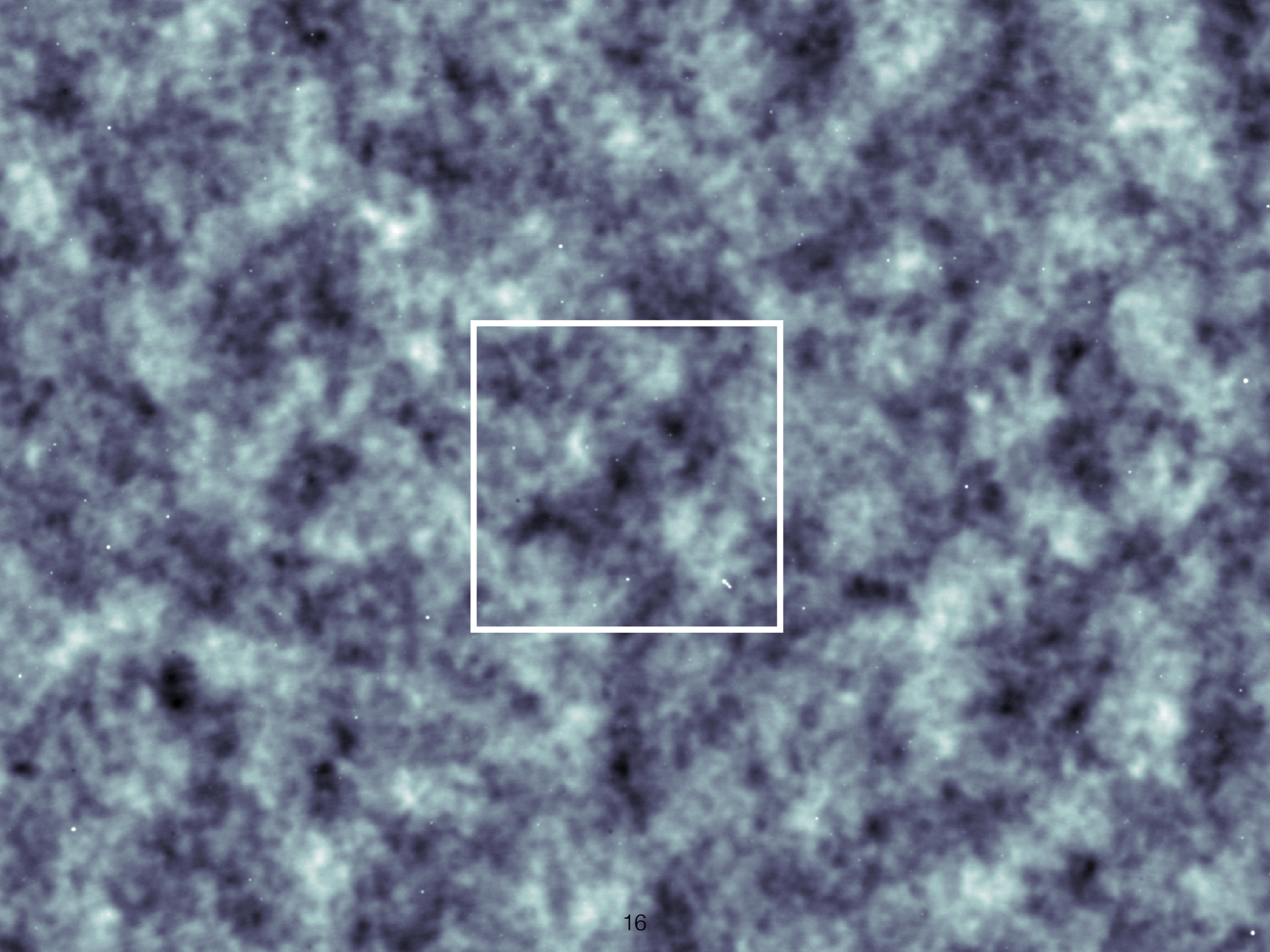
x10 depth



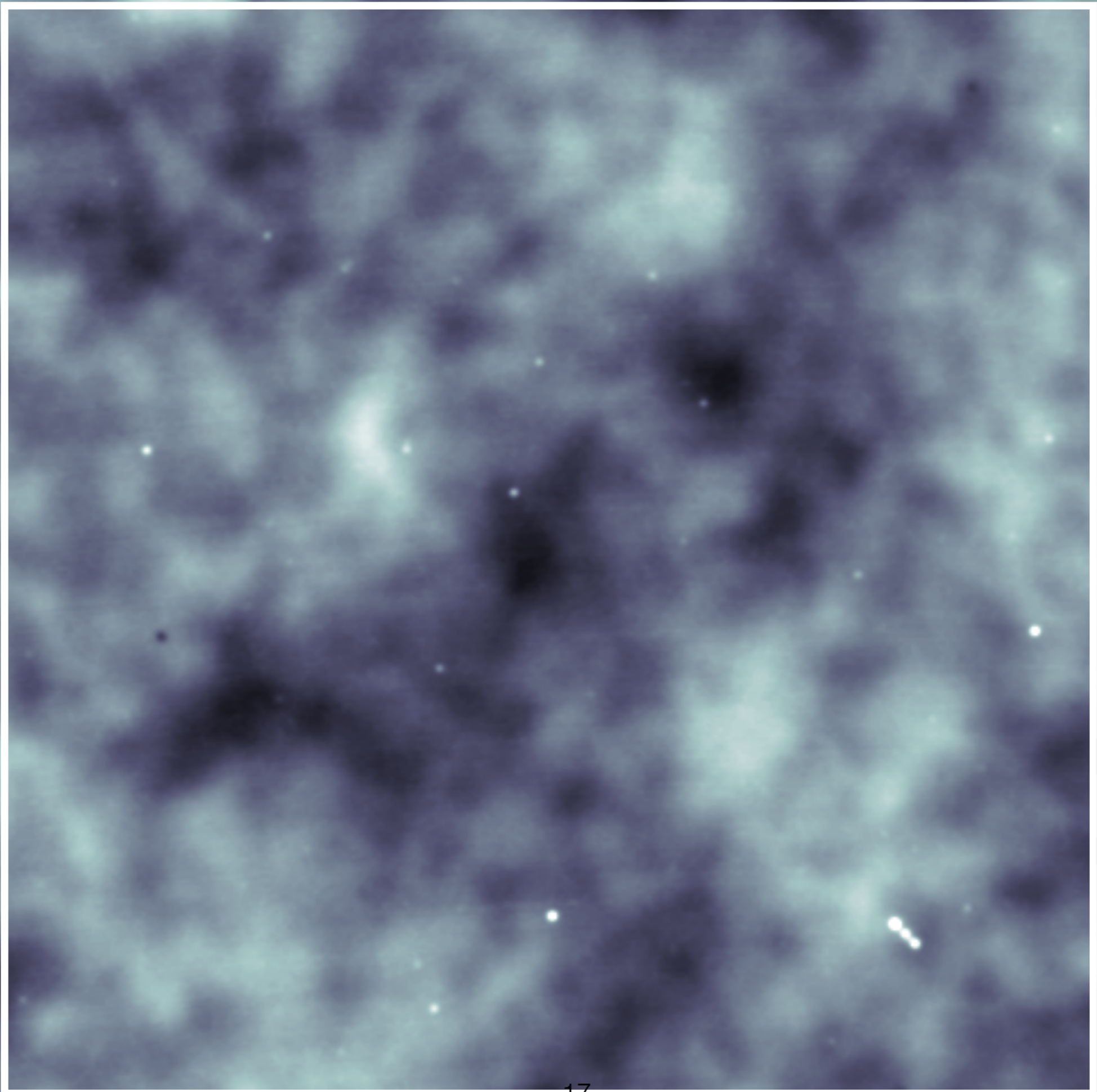
SPTpol  
500 deg<sup>2</sup>  
150 GHz / 2 mm

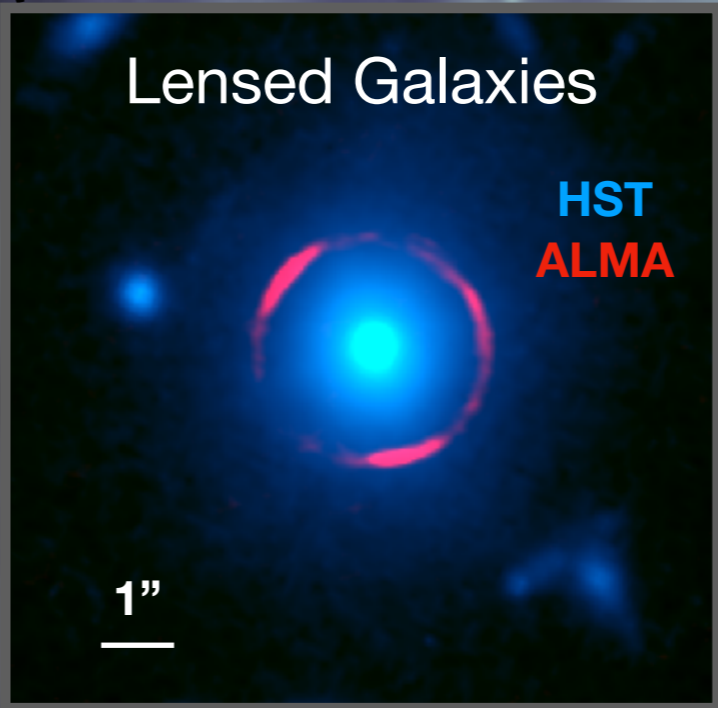
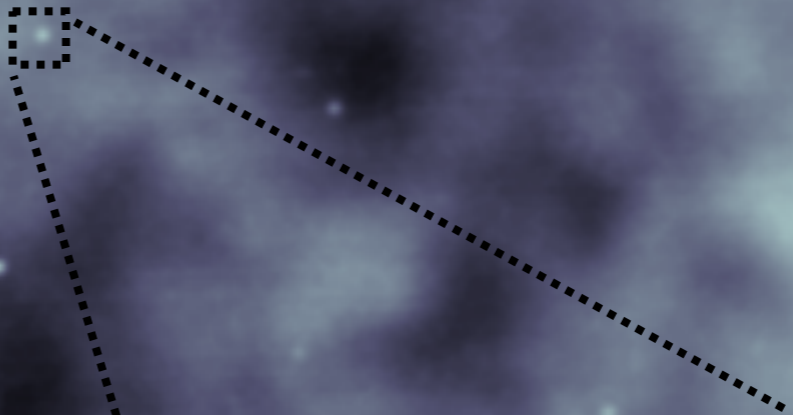
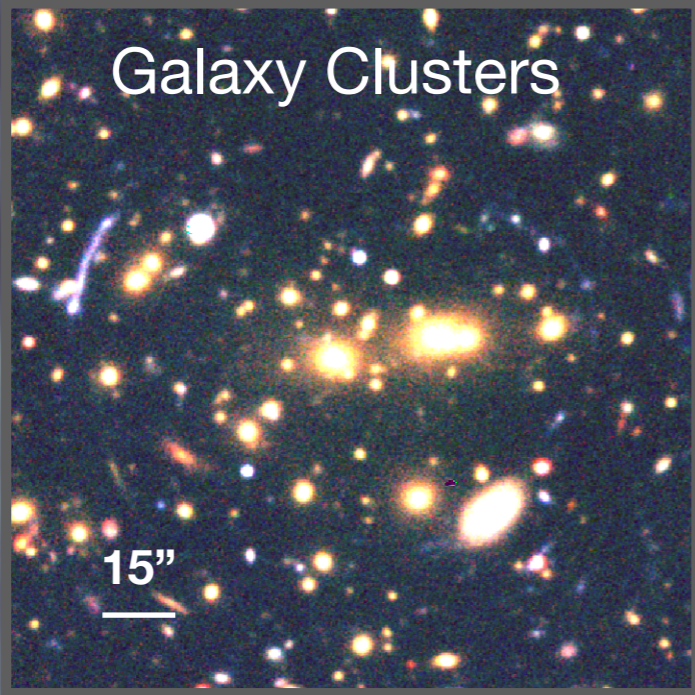


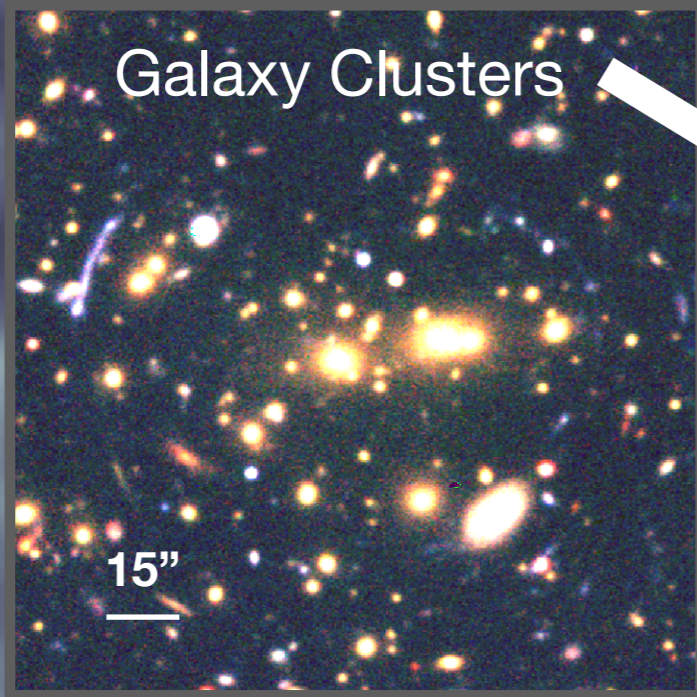
SP1 poi  
500 deg<sup>2</sup>  
150 GHz / 2 mm



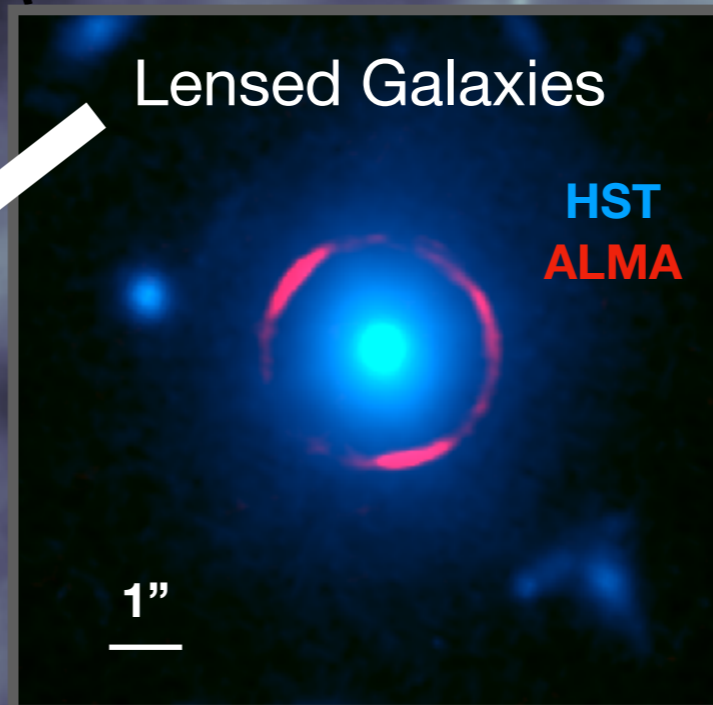








**Dark Energy**



**the first galaxies**

# ALMA: The Atacama Large (sub) Millimeter Array



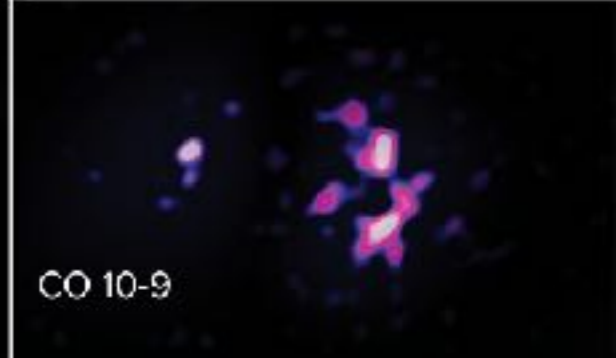
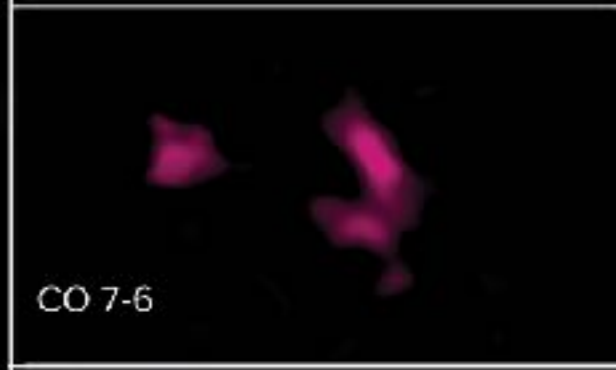
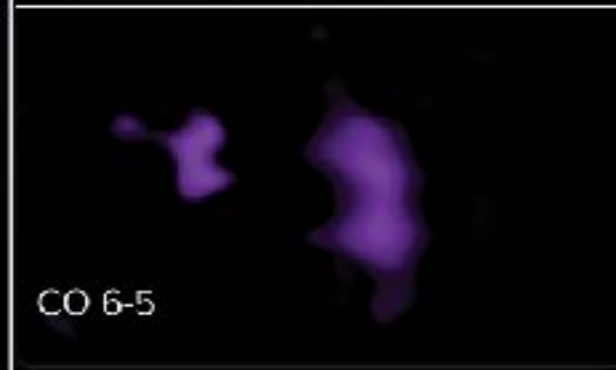
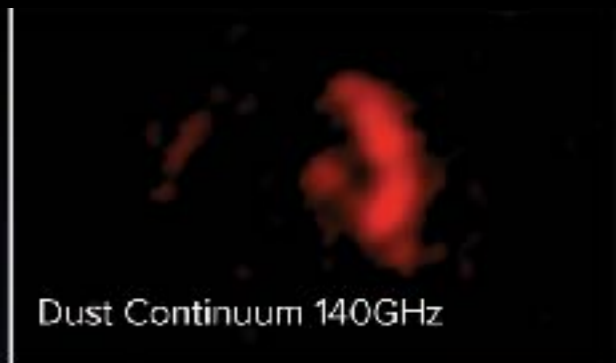
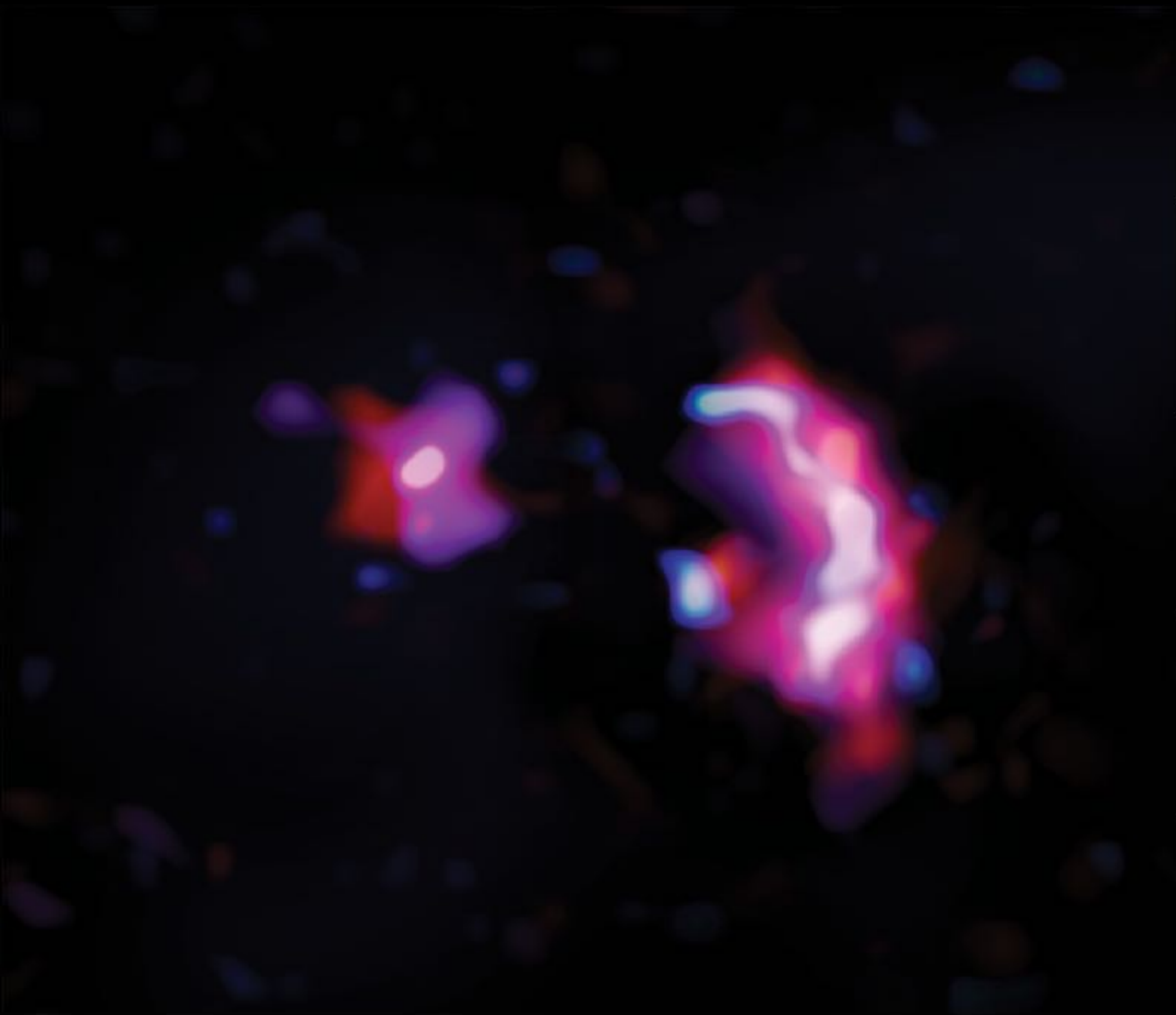
See:  
*Vieira et al. 2013, Nature*



# ALMA Cycle 5 image of SPT0311-52 160um rest-frame continuum



The **most detailed** look at the redshift  $\sim 7$  Universe !  
800M years after Big Bang !  
This is what ALMA was **MADE** to do !



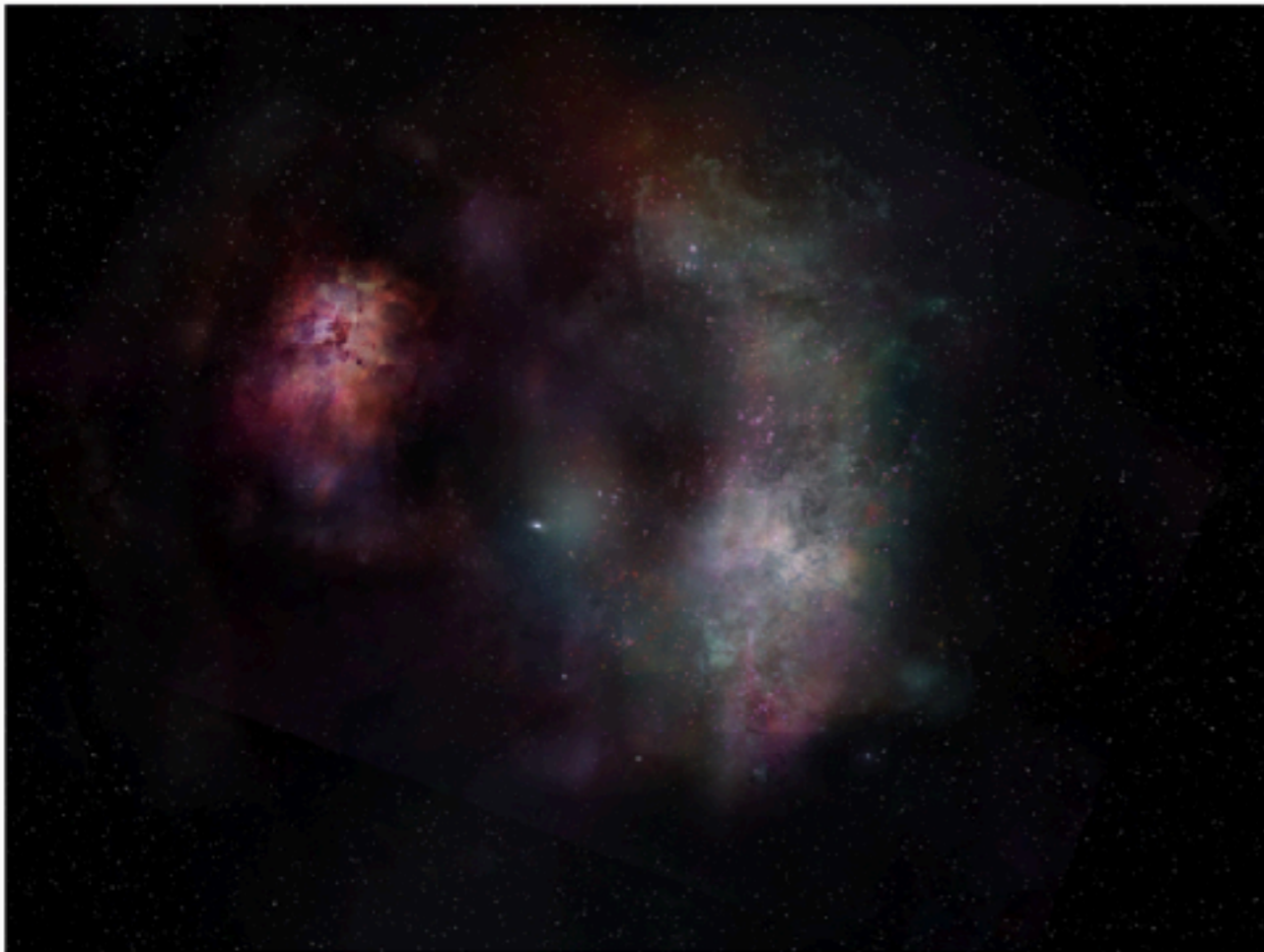


National Radio  
Astronomy  
Observatory



## ALMA Scientists Detect Signs of Water in a Galaxy Far, Far Away

New study marks most distant detection of required element for life as we know it in a regular star-forming galaxy



Credit: ALMA (ESO/NAOJ/NRAO)/S. Dagnello (NRAO)

INVERSE

PASSANT RABIE

11.3.2021 6:00 PM

ANZOUZIL RABIE

## SCIENTISTS JUST FOUND WATER IN THE MOST DISTANT PART OF THE UNIVERSE SO FAR

How it got there remains a mystery.

**THE EARLY UNIVERSE IS SHROUDED IN MYSTERY.** But every now and then, astronomers get a peek at what the cosmos were like by peering back in time at distant, ancient galaxies. And galaxy SPT0311-58 just proved how much scientists don't know about the young universe.



USA TODAY

Subscribe Sign In

### Water has been detected in a galaxy roughly 12.8 billion light years away, researchers say

JORDAN MENDOZA | USA TODAY | 4:15 pm EDT November 3, 2021



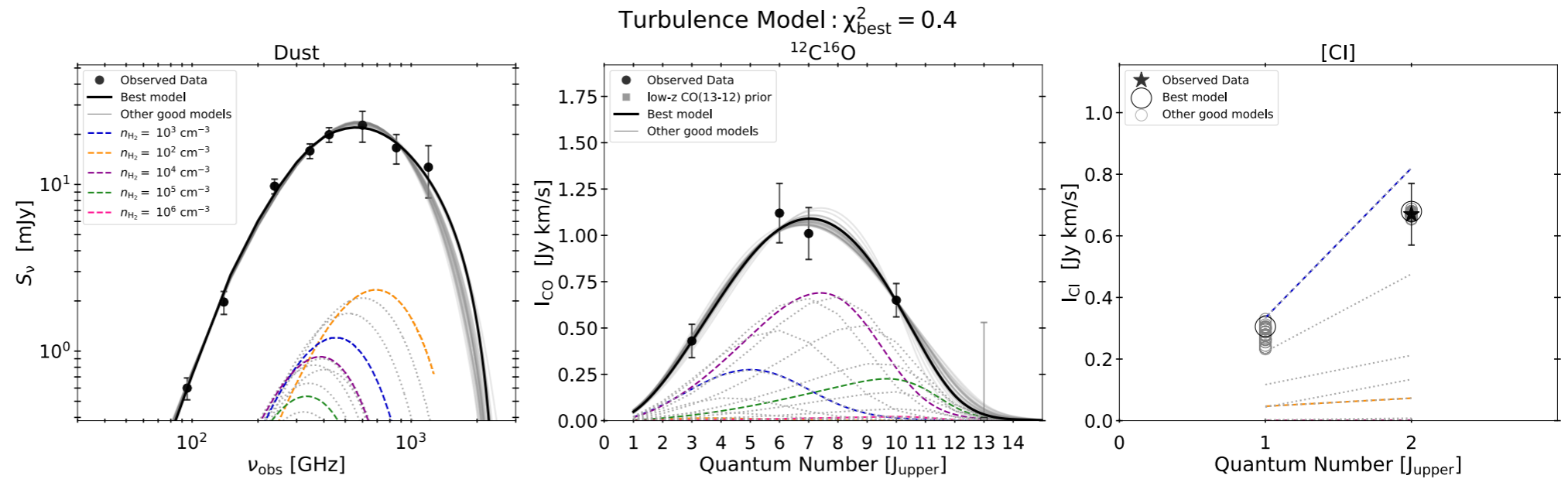
# Observing Molecules at $z = 6.9$ – 800 Myr after Big Bang



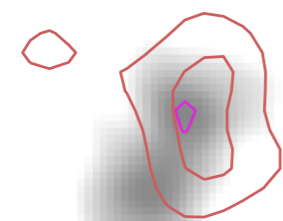
**I**LLINOIS

graduate student  
Sreevani Jarugula

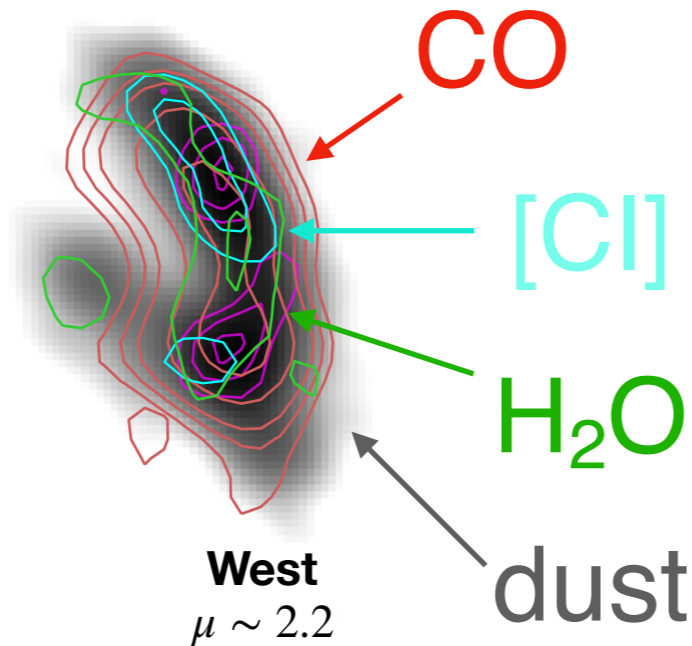
Jarugula, Vieira, *et al.*, *ApJ*, 2021



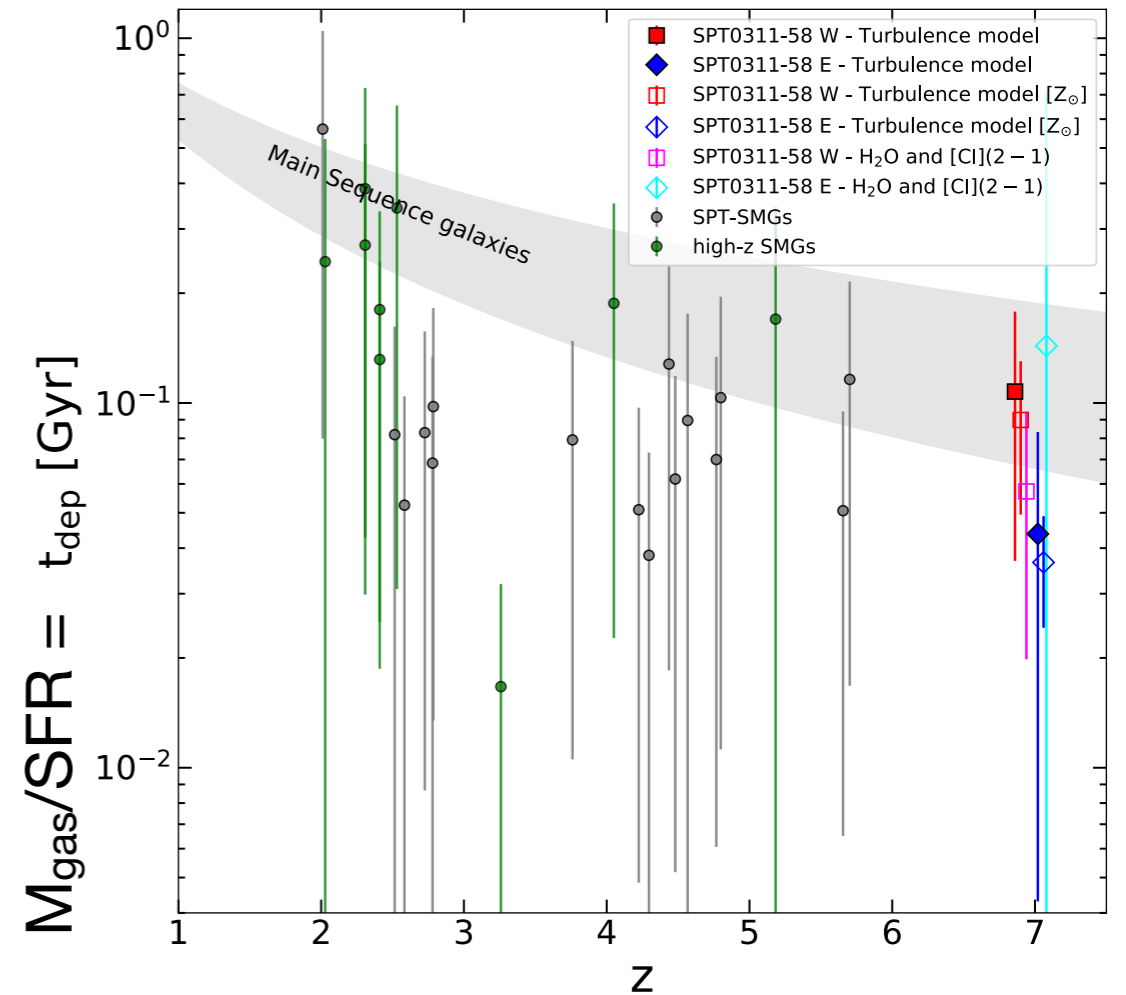
CO(6-5)  
CO(10-9)  
p-H<sub>2</sub>O(2<sub>1,1</sub>-2<sub>0,2</sub>)  
[CI](2-1)



East  
 $\mu \sim 1.3$



West  
 $\mu \sim 2.2$

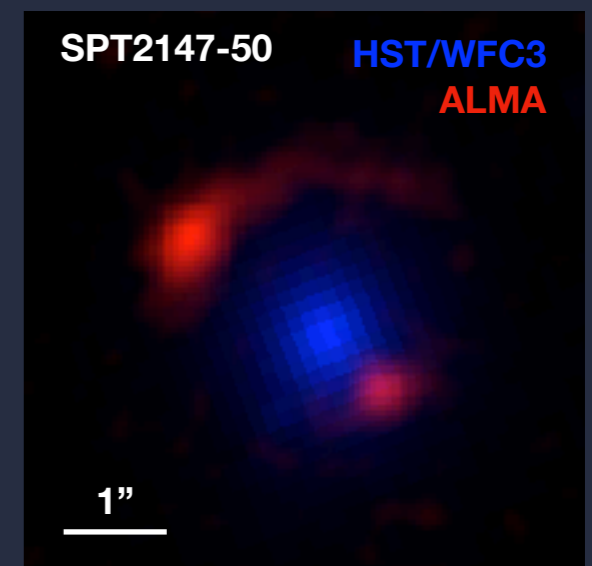
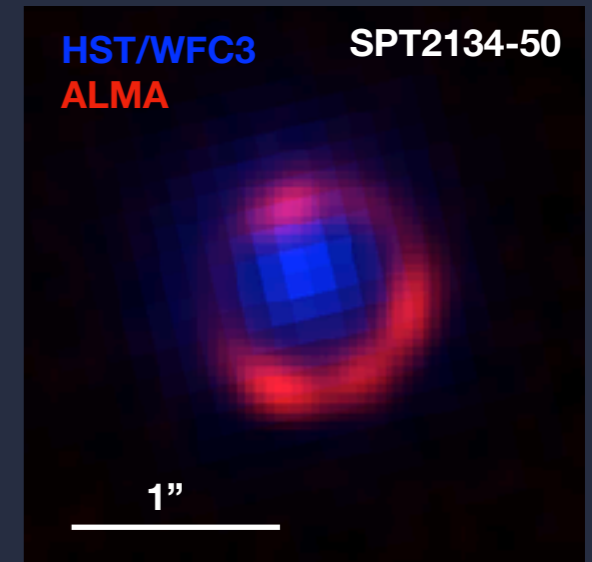






# James Webb Space Telescope

launches 18 December 2021 (!?!?!)



## JWST Early Release Science (ERS) Program

TEMPLATES: Targeting Extremely Magnified Panchromatic Lensed Arcs and Their Extended Star formation

PI: Jane Rigby (NASA Goddard) ; Co-PI: Joaquin Vieira (U. Illinois)

55 hours of Director's time

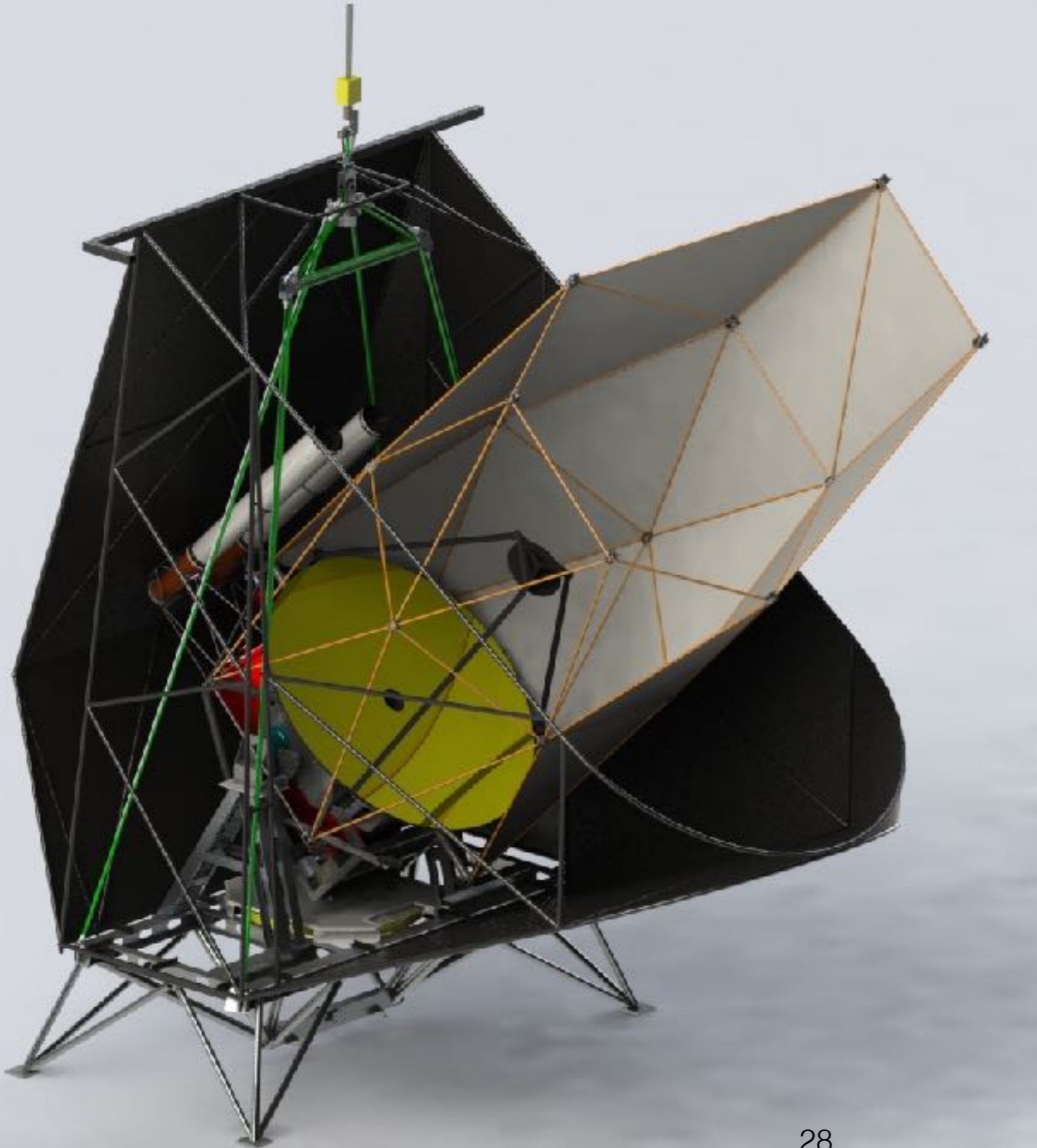


this selfie was taken at 5 km / 16,600 ft on the Atacama Plateau c. 2010  
I was a 32 year old postdoc at Caltech.  
I was putting a new camera on a telescope in Chile.

APEX Telescope  
Atacama, Chile  
c. 2010

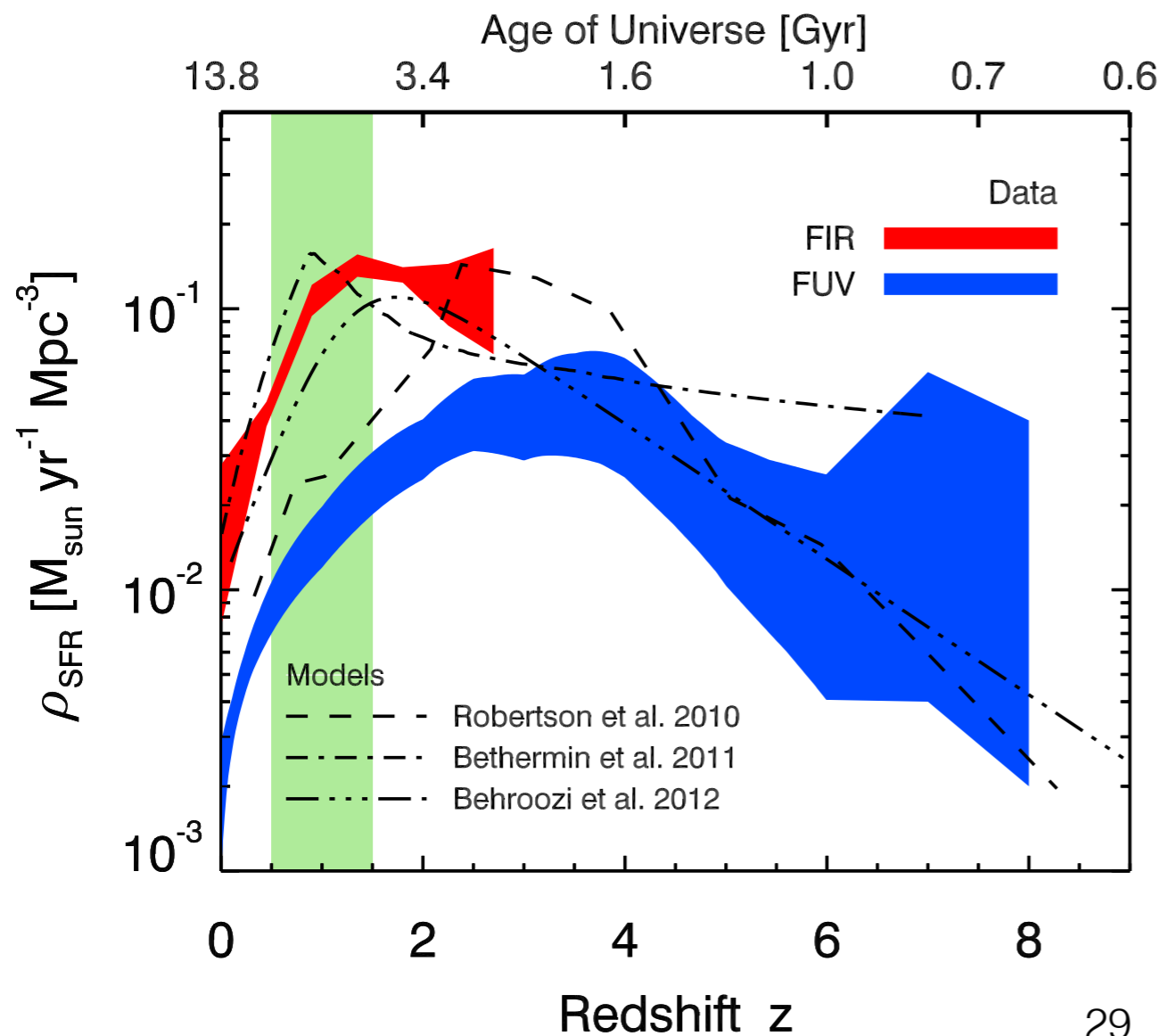
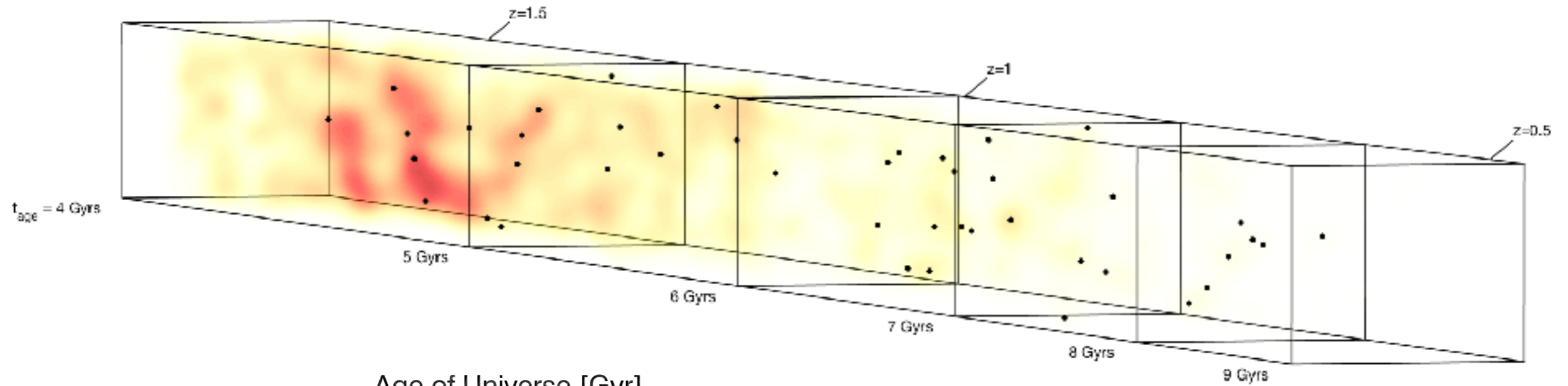


# The Terahertz Intensity Mapper (TIM)



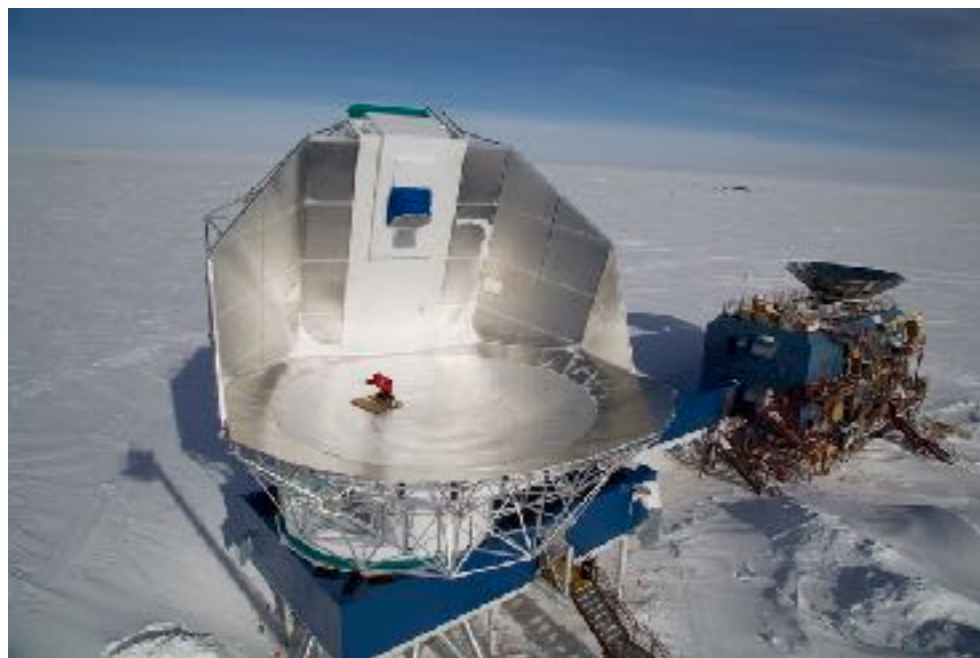
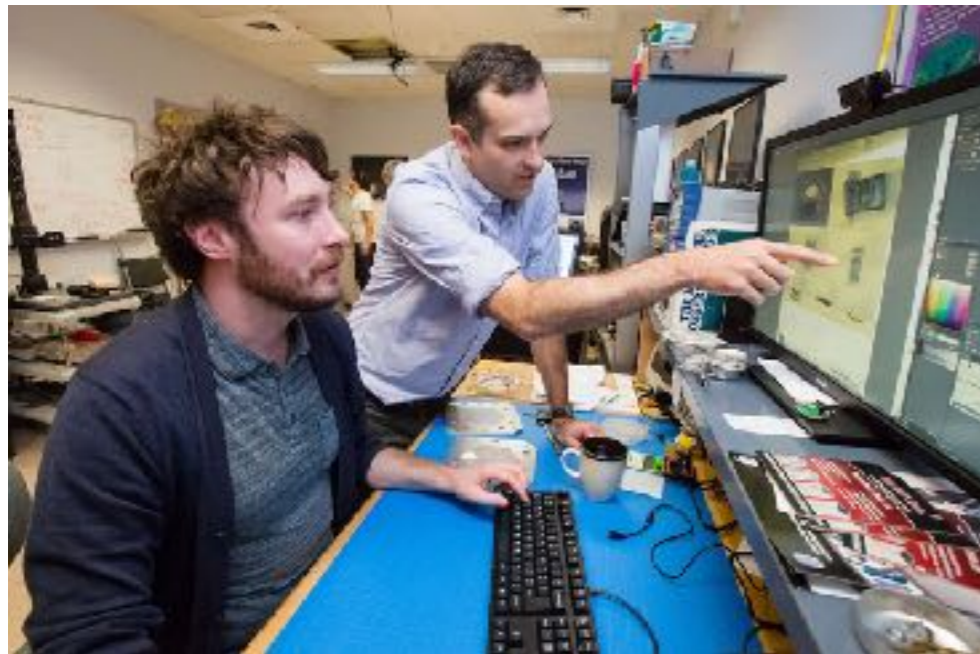
- 2m primary mirror
- 240–420 $\mu\text{m}$  IFU spectrometer
- 6600 detectors (KIDs)
  - 64 x 2 spectral channels
  - 51 spatial channels
- [CII]158 $\mu\text{m}$  from  $0.5 < z < 1.5$
- Anticipated launch winter 2024
- PI: J. Vieira (U. Illinois)
- see: [arXiv:2009.14340](https://arxiv.org/abs/2009.14340)

# The Terahertz Intensity Mapper (TIM)



We will spectroscopically measure the cosmic star formation history for the first time





# **I** ILLINOIS **Observational Cosmology**

September 2021





# Graduate School for Astronomy / Physics



# “To be or not to be” (a grad student)

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## Did you enjoy your undergraduate research experience?

Graduate school is (almost) all about research. You must be willing to invest the time (typically 5-6 years) and long hours to get a PhD.

## Do the research areas you have been hearing about sound interesting?

It's important for you to expose yourself to all the different research areas, to see if anything strikes your fancy!

## Does the open-ended nature of research appeal to you?

You'll have guides in your research, but no experts who'll know the answer for sure!

## Are you resilient and not easily distracted or deterred?

You'll definitely run into road blocks in research, and you'll need to pull yourself through

# Before you apply

- Think about what you WANT to do in LIFE.
- Jobs are HARD to get in academia. You have to put your life on hold.
- Have a REASON to go to grad school.
- Advice: Take time off. Mature. Gain experience. It's your last chance.

# caveats

- Grad school is HARD. Not the work. Everything else.
- Grad school is LONG. ~7 years. It will eat up the best years of your life.
- Grad school is NOT GLAMOROUS. You get paid very little, work a lot.
- That said, a higher degree in physics or astronomy will set you up for a comfortable and fulfilling life.

# HOW GRAD SCHOOL IS JUST LIKE KINDERGARTEN

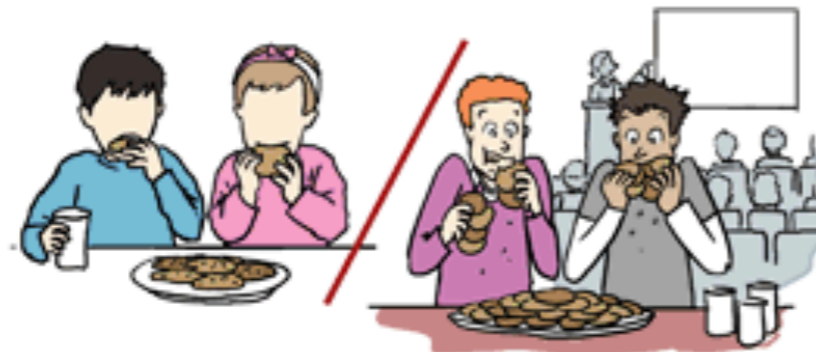
ALL DAY NAPPING IS ACCEPTABLE



THERE IS CONSTANT ADULT SUPERVISION



YOU GET COOKIES FOR LUNCH



MOST COMMON ACTIVITY:  
CUTTING AND PASTING



THERE ARE NO GRADES  
(YOU JUST HAVE TO PLAY WELL WITH OTHERS)



CRYING FOR YOUR MOMMY IS NORMAL



JORGE CHAM © 2010

# THE BEST YEARS OF YOUR LIFE

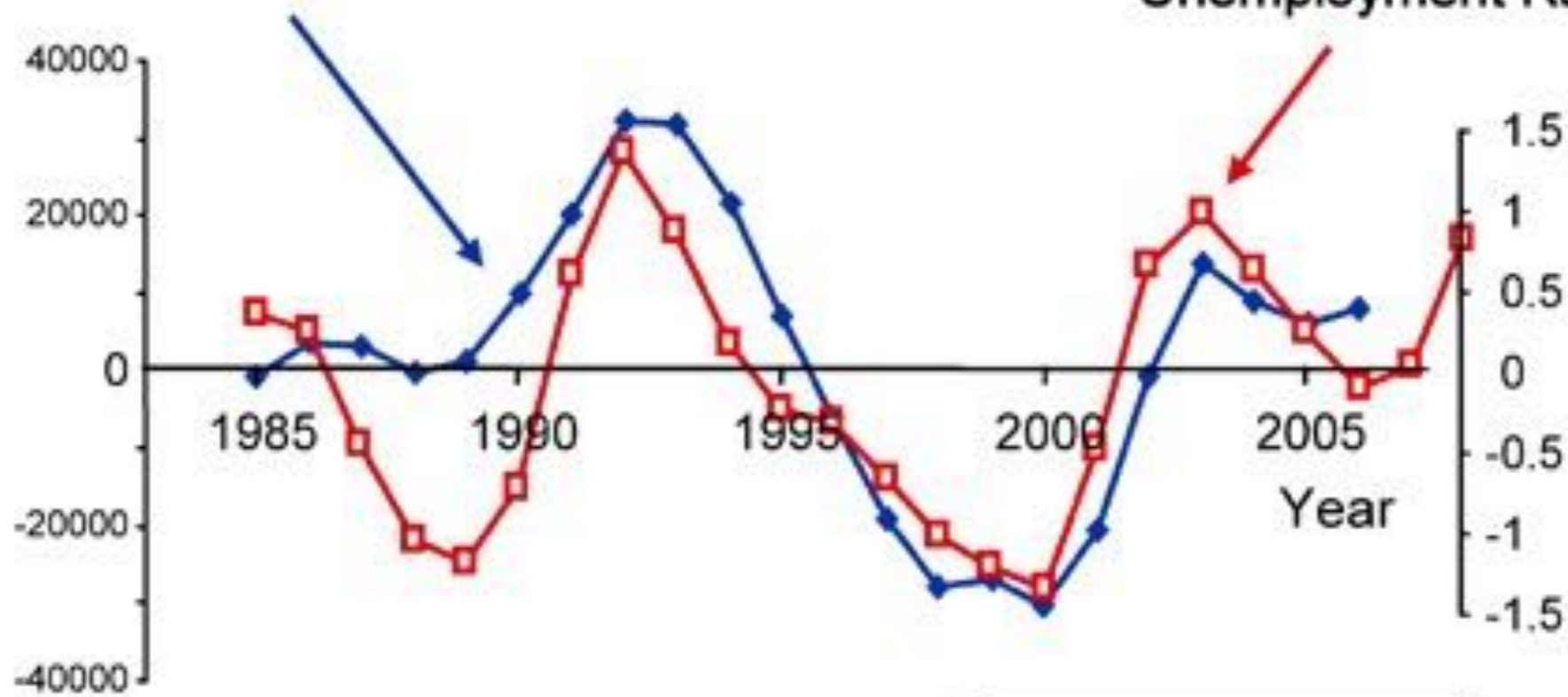


JORGE CHAM © 2013

[WWW.PHDCOMICS.COM](http://WWW.PHDCOMICS.COM)

## Fluctuations in Grad Student Enrollment (Science & Engineering)

## Fluctuations in the Unemployment Rate



Correlation Coefficient:

$$\rho = 0.75583$$

(that's pretty high)

JORGE CHAM © 2008

grad school is for suckers! wall street here i come!



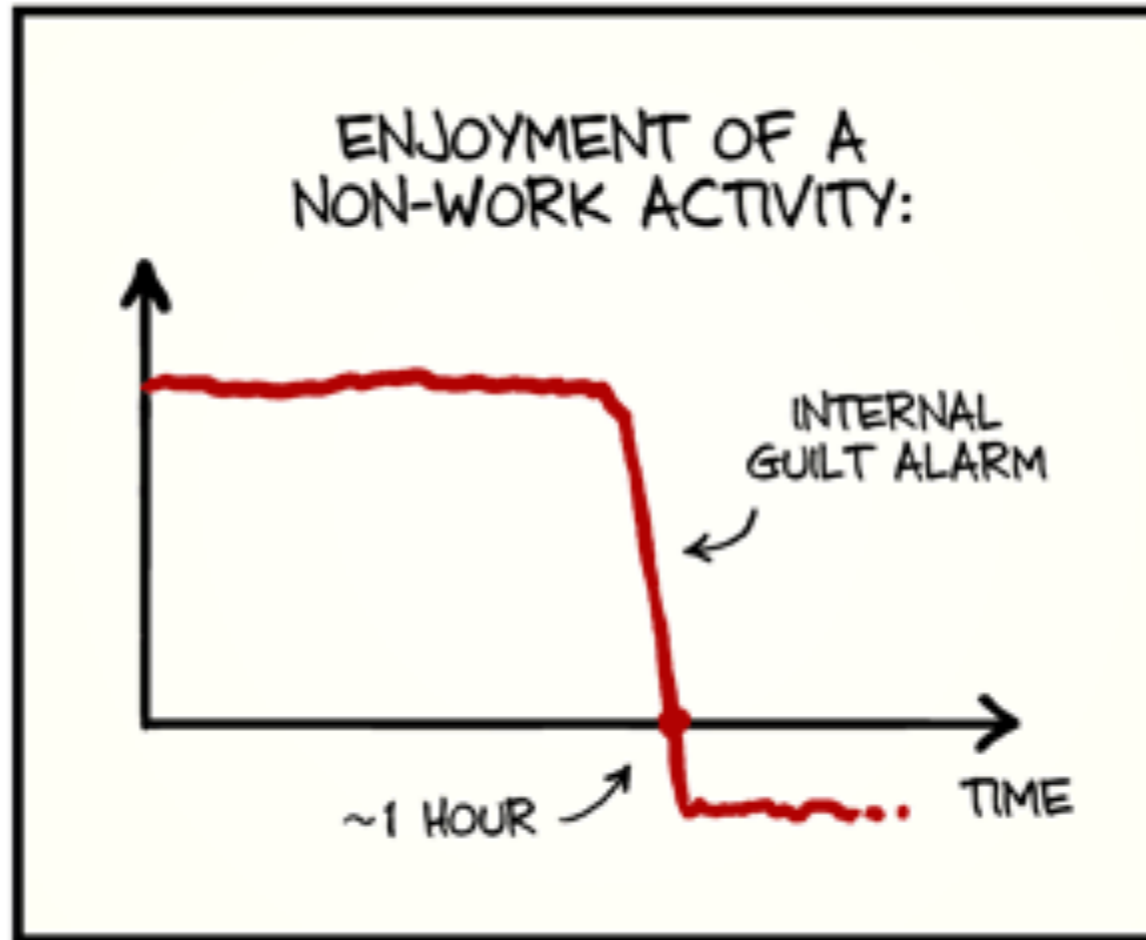
## Guess Who's Coming to Grad School?

Sources: NSF/Bureau of Labor Statistics. Fluctuations obtained by subtracting the mean regression line from the absolute values.

i always wanted to go to grad school...



WWW.PHDCOMICS.COM



WWW.PHDCOMICS.COM



# Alternative opportunities for PhDs in Astronomy & Physics

- Aerospace (e.g. SpaceX, Lockheed, JPL, etc)
- Data Science
- Finance
- Tech (Apple, quantum computing)
- Basic R&D (HP, Lincoln Labs, etc)
- Teaching

# Me as a case study

- UCLA undergrad (astrophysics)
  - 2.95 gpa
  - 16th percentile physics GRE
- U. Chicago grad school (physics)

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WARNING:  
Do not do it  
how I did it

# What you need to apply to grad schools:

- ✓ **grades**
- ✓ **GRE**
- ✓ **CV**
- ✓ **personal statement**
- ✓ **3 letters of reference**
- ✓ **research**
- ✓ **grit**

# grades

- show improvement over time
- get an A in quantum
- take hard classes

# GREs

The GREs have gone in and out of fashion over the years.

In particular, the Physics subject GRE is nearly gone.

The General GRE is still sometimes used.

Some people put more weight on verbal GREs because it gives important clues about:

- 1) whether a student will be able to write a coherent paper,
- 2) whether a student can understand the arguments in scientific papers (which are often highly obscured by jargon, math, and other things)
- 3) whether they can approach problems critically and break down research puzzles into the components necessary to make progress (which I think is supposed to be measured by the analytic part, but doesn't seem to be).

# Letters of Reference

How to choose letter writers?

Research is most important.

- Think about what they would say (write a letter for yourself as practice!)
- Talk to them
- Give them cv
- Be organized.
- Think about “cultivating” letter writers over the course of your career.
- (Understand that it is a LOT of work to write these letters.)

# What happens on the grad admissions committee?

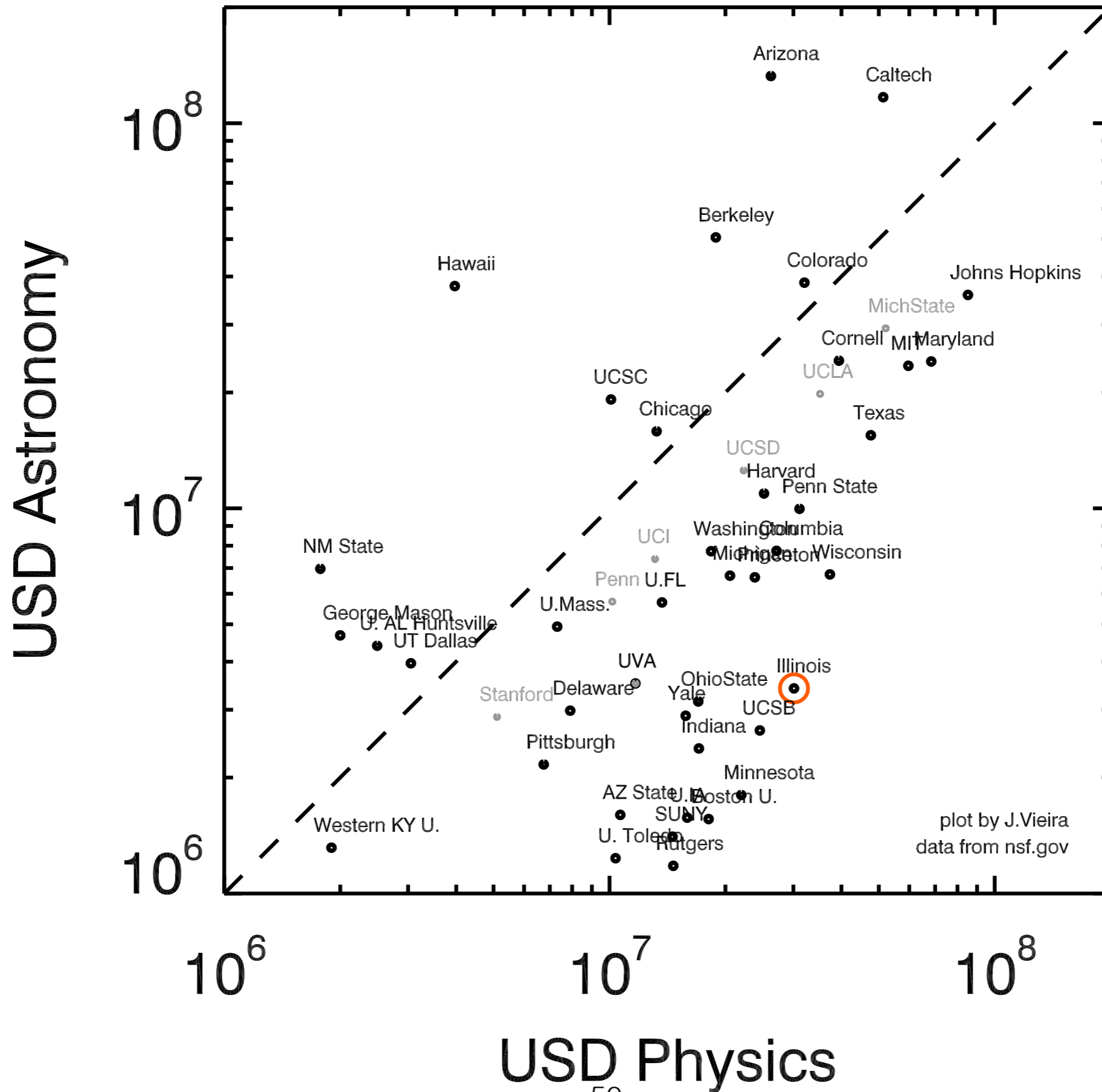
Remember:

- The committee is in an information VACUUM
- They are acting in their self-interest to find the best grad students to do research.
- The process is very stochastic.



# How to choose a grad school

# R&D expenditures FY2012



# How to choose a grad school

1. [As a first year grad student:] Choose a project and advisor. (You will spend ~7 years with them...)

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3. [As a postdoc:] Best school possible. (Better opportunities.)

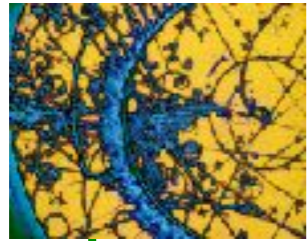
# How to choose a grad school

1. [As a first year grad student:] Choose a project and advisor. (You will spend ~7 years with them...)
2. [As a 4th year grad student:] Location ! (You will have to live there for 7 years...)
3. [As a postdoc:] Best school possible. (Better opportunities.)
4. [As a professor:] Who knows ?! (Depends on too many variables)

# Advice to young scientists

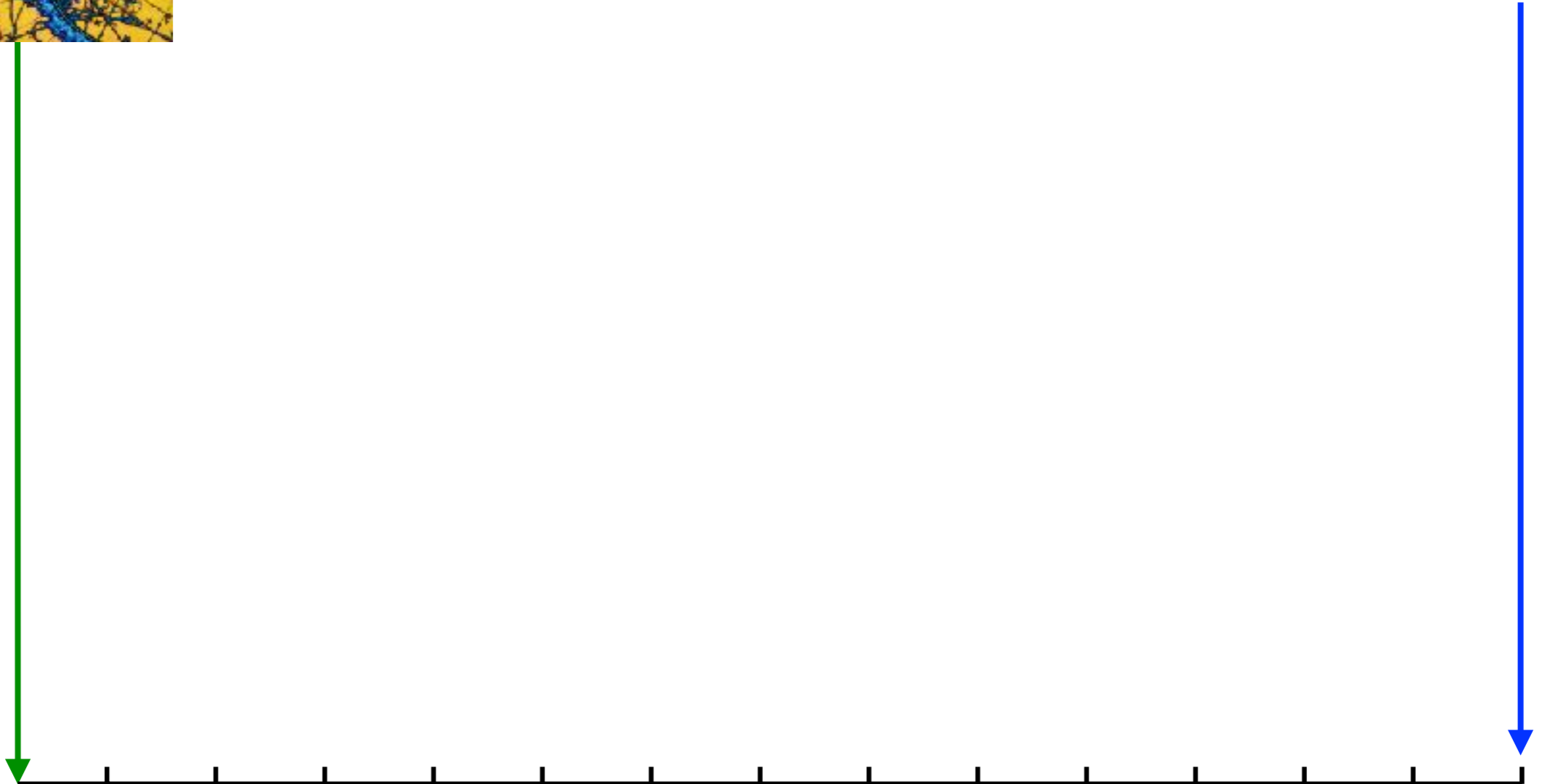
- Be curious. (Why else would you be in science?)
- Be honest and careful. (Reputation matters.)
- Learn to take criticism. (Lose your ego.)
- Learn from your mistakes. (Only make them once.)
- Ideas are cheap. Implementation is expensive. (Everyone is smart, so you have to work hard and efficiently.)
- Make good science. (Everything else will take care of itself.)
- Be nice, make friends. Learn from your peers. (Science is collaborative.)
- Have fun. (It's a shitty job unless it's fun.)

# Cosmological Time



**Universe Began**  
**~13.7 billion years ago**

**NOW**  
**on**  
**EARTH**

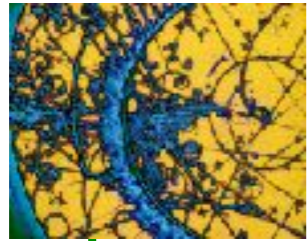


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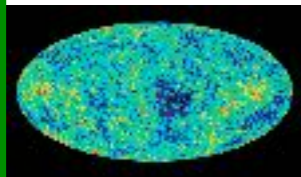
cosmic time [billions of years]



# Cosmological Time

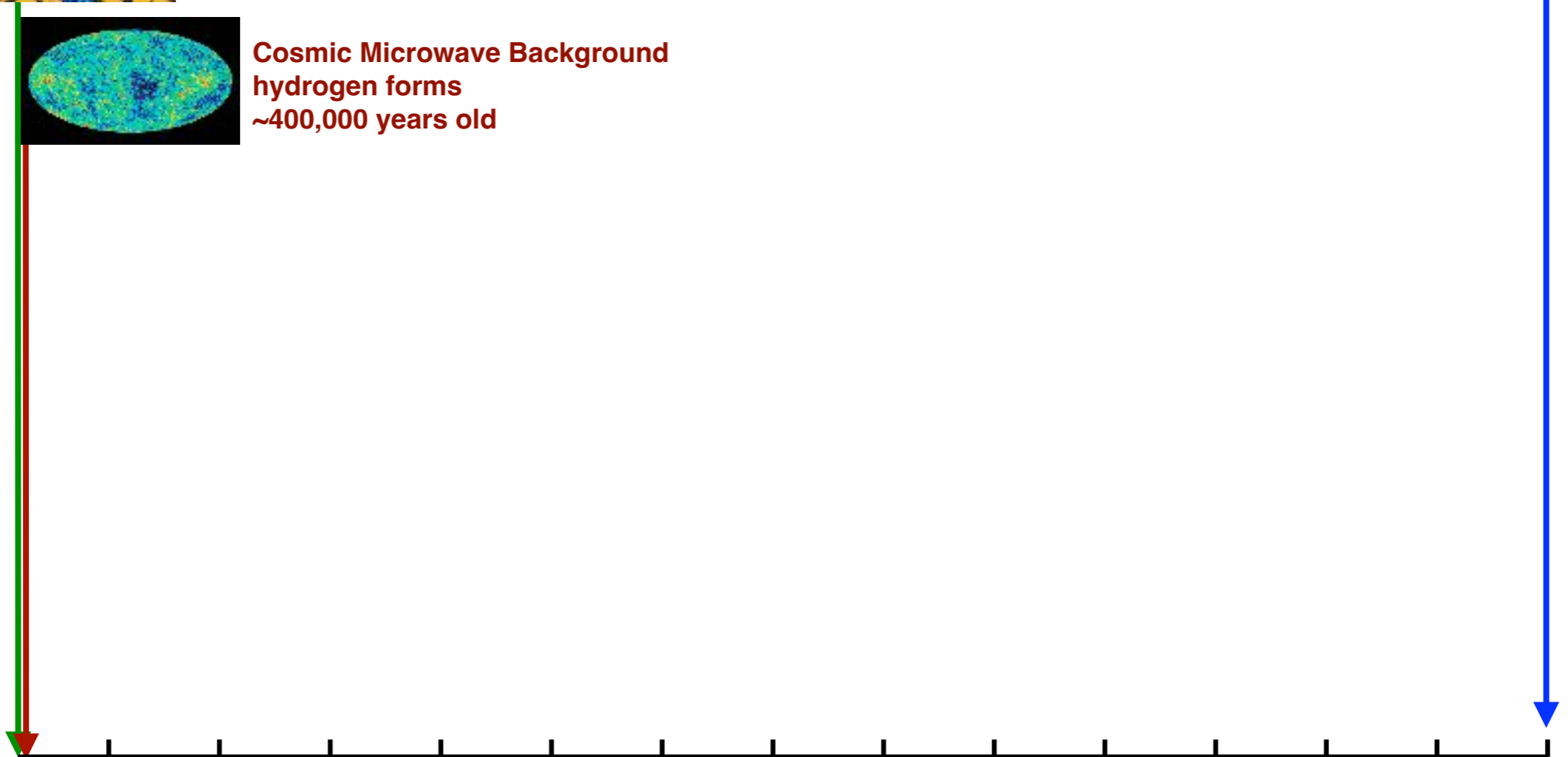


**Universe Began**  
**~13.7 billion years ago**



**Cosmic Microwave Background**  
**hydrogen forms**  
**~400,000 years old**

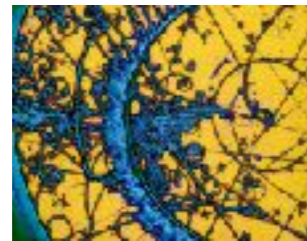
**NOW**  
**on**  
**EARTH**



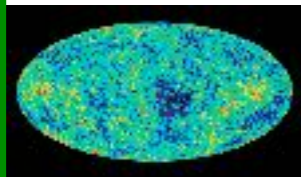
13 12 11 10 9 8 7 6 5 4 3 2 1 0

cosmic time [billions of years]

# Cosmological Time



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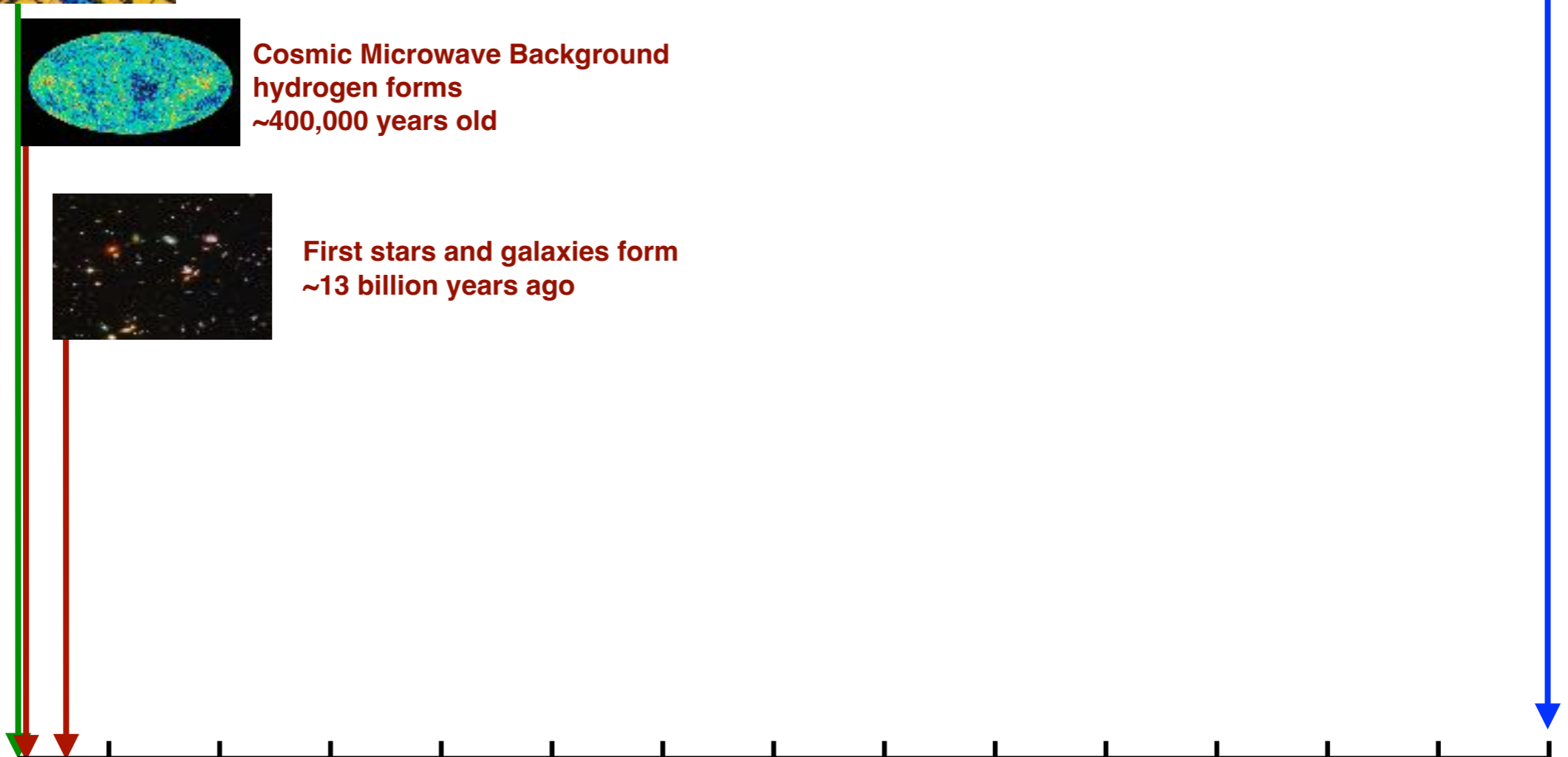


**Cosmic Microwave Background  
hydrogen forms**  
**~400,000 years old**



**First stars and galaxies form**  
**~13 billion years ago**

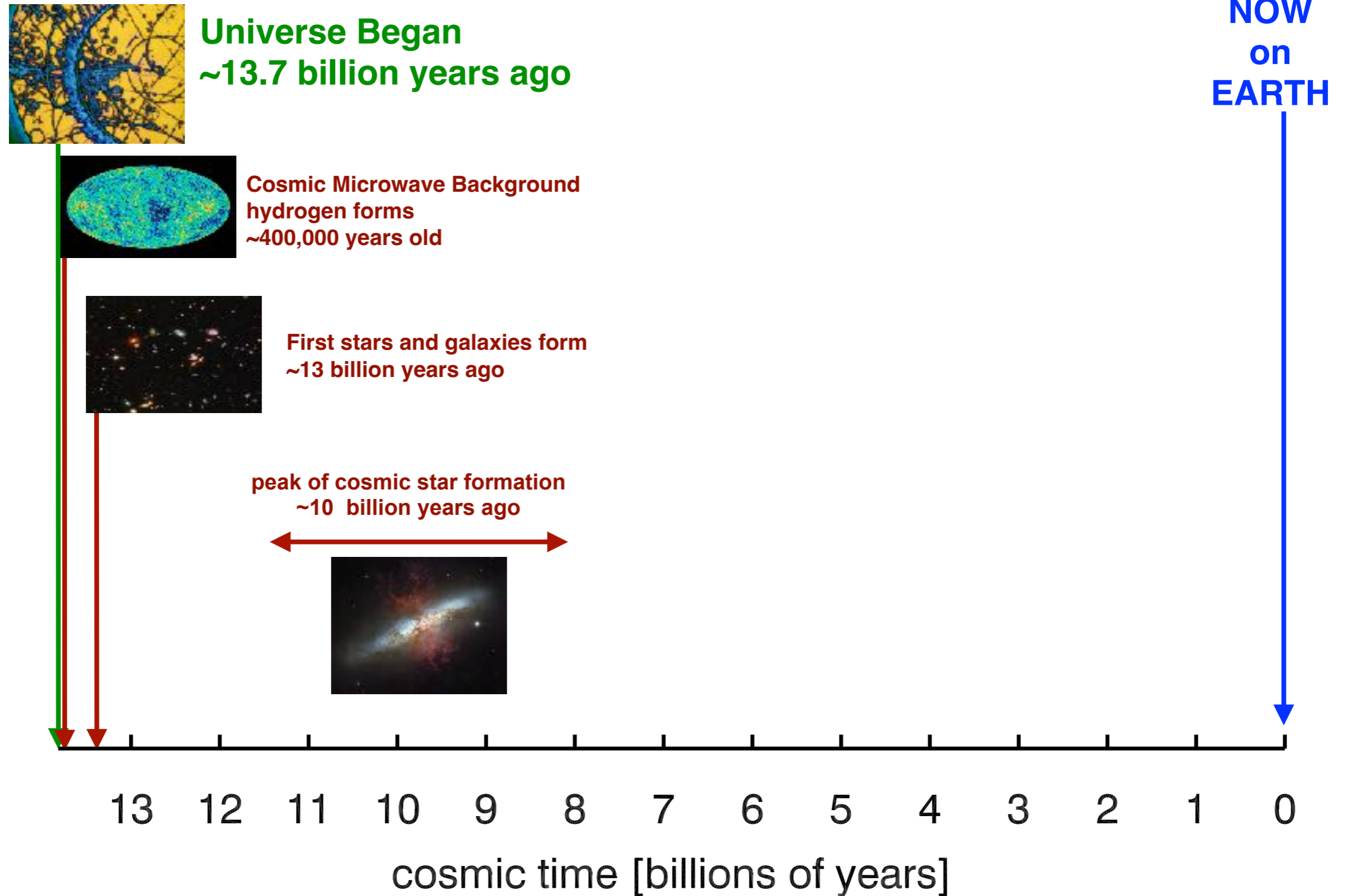
**NOW  
on  
EARTH**



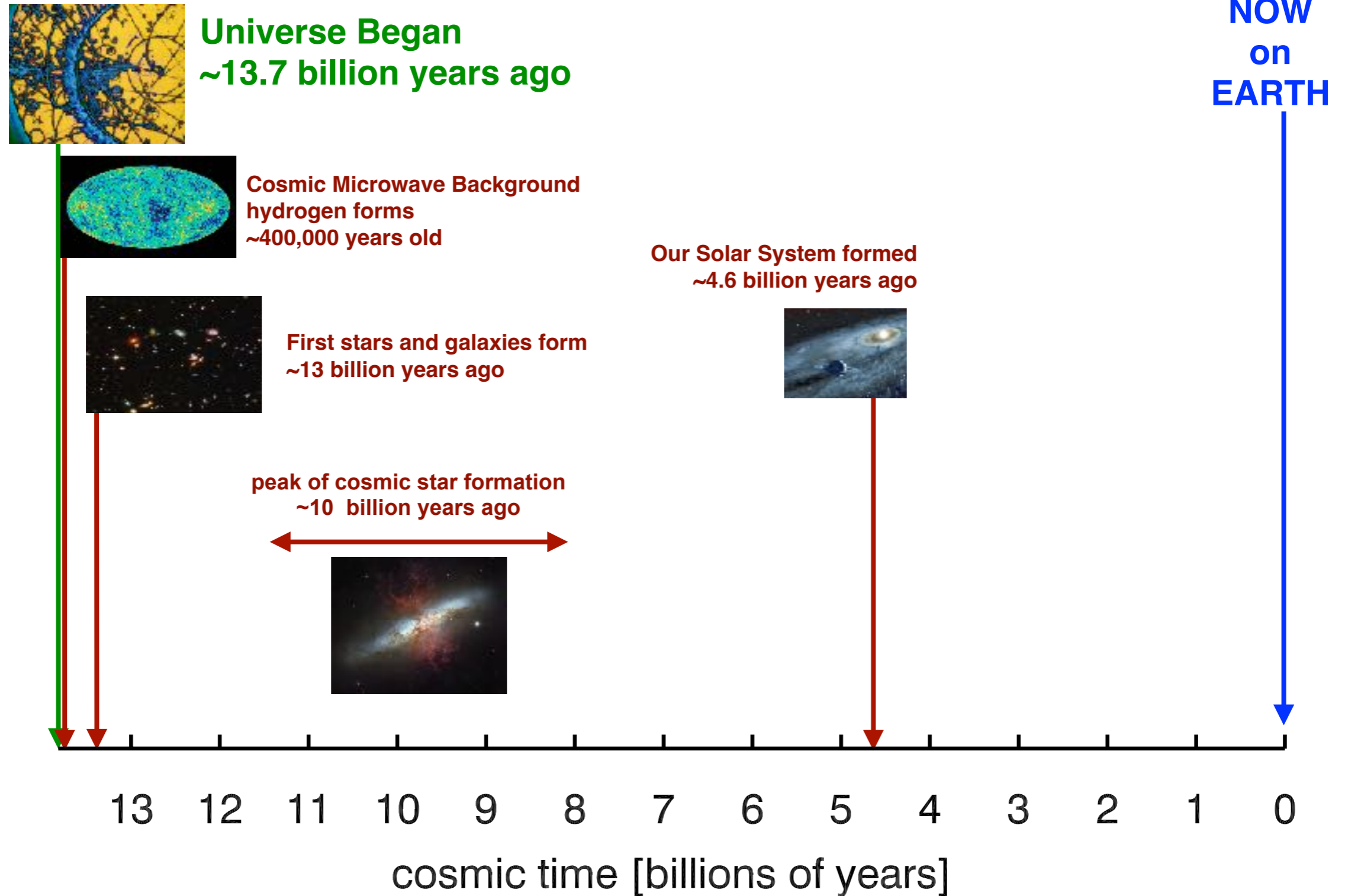
13 12 11 10 9 8 7 6 5 4 3 2 1 0

cosmic time [billions of years]

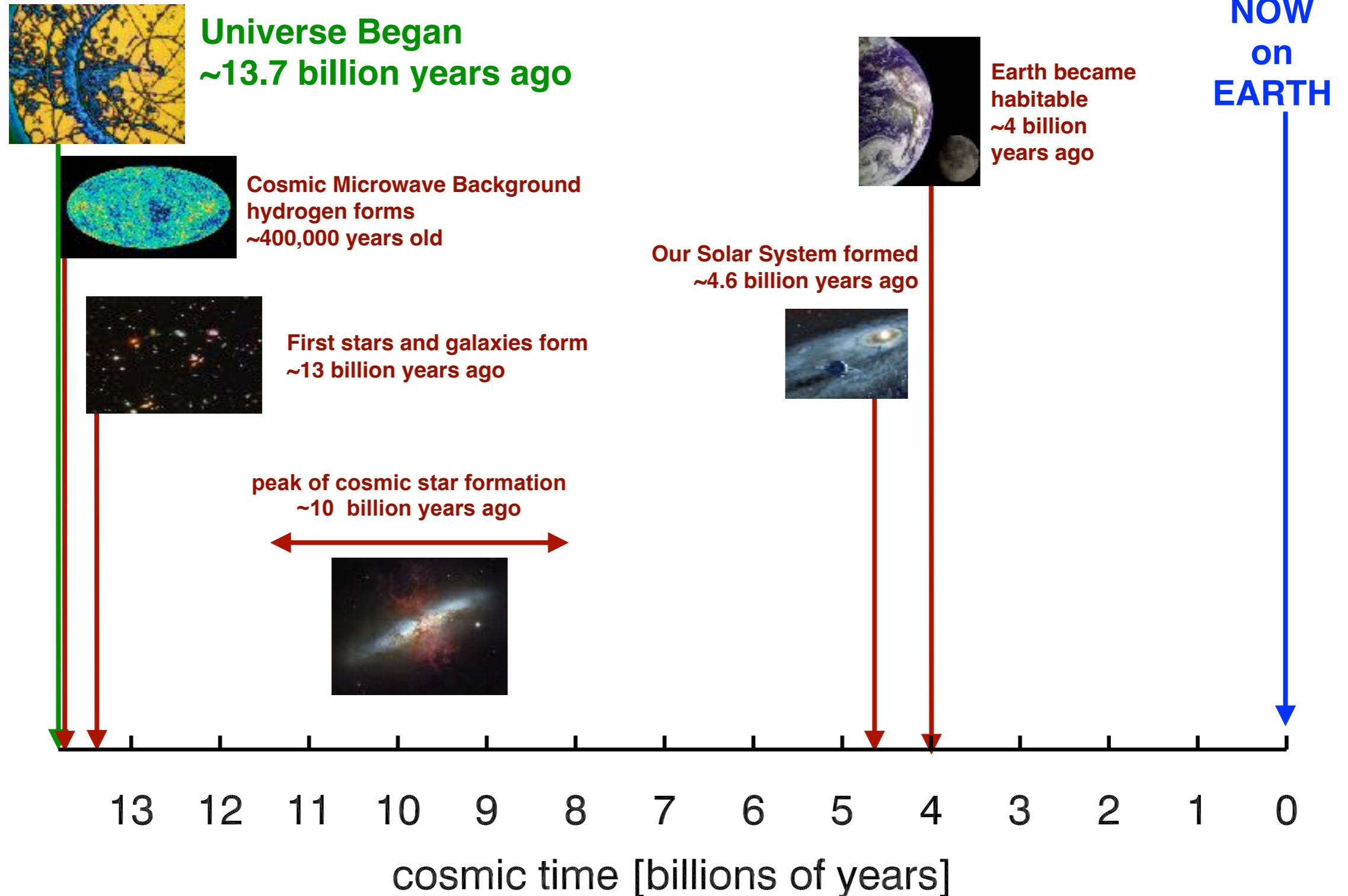
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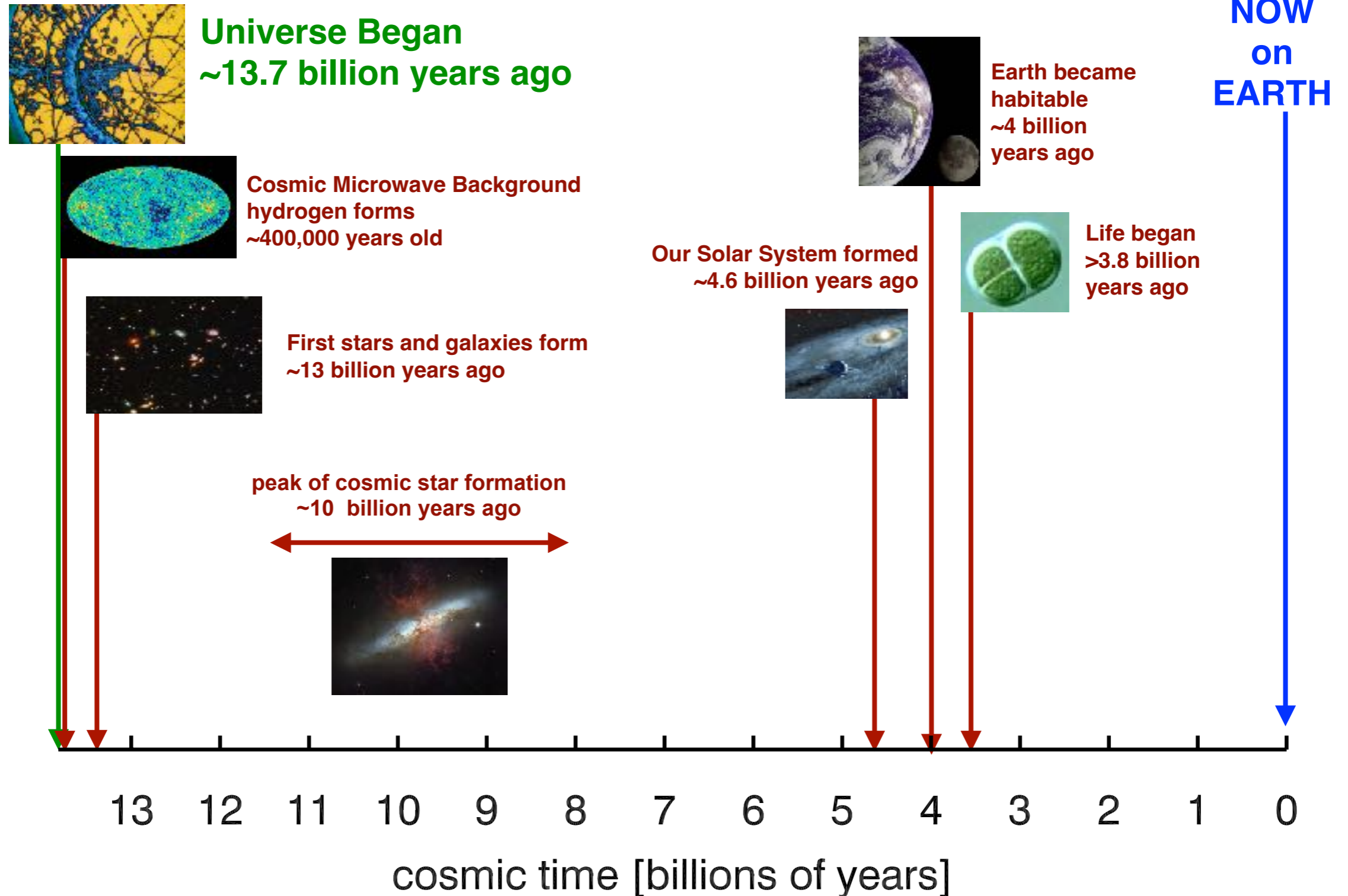
# Cosmological Time



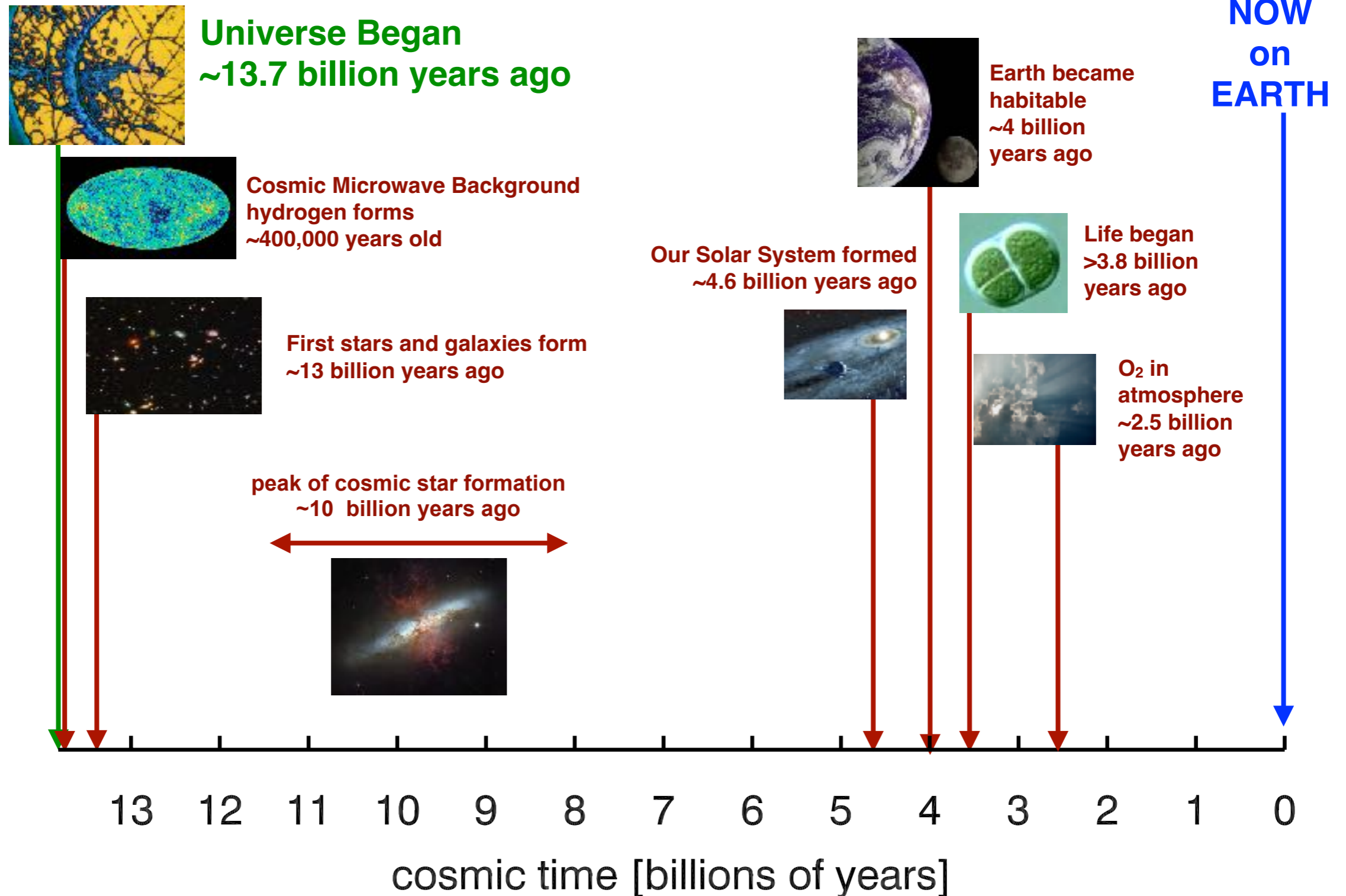
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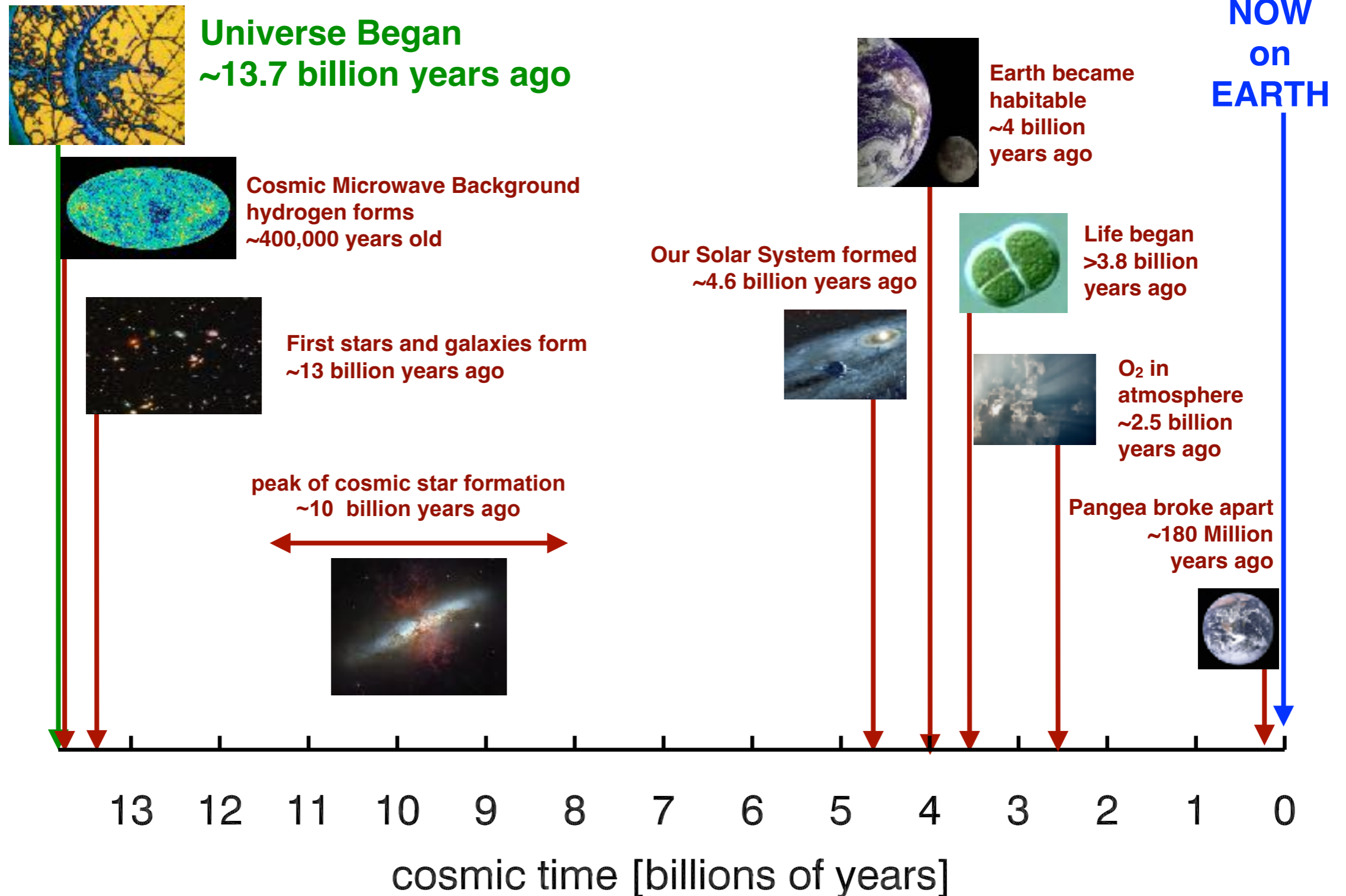
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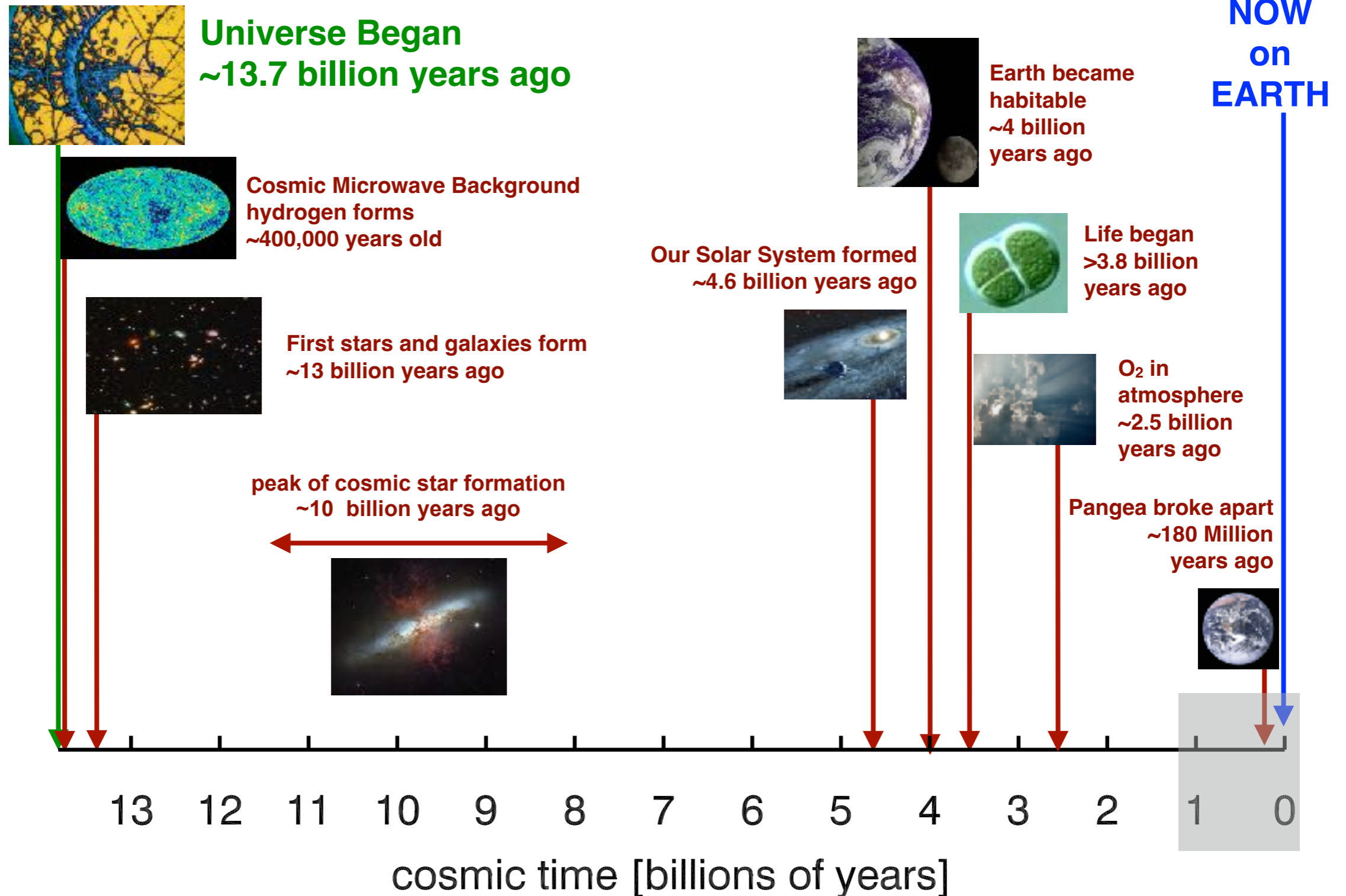


# Cosmological Time

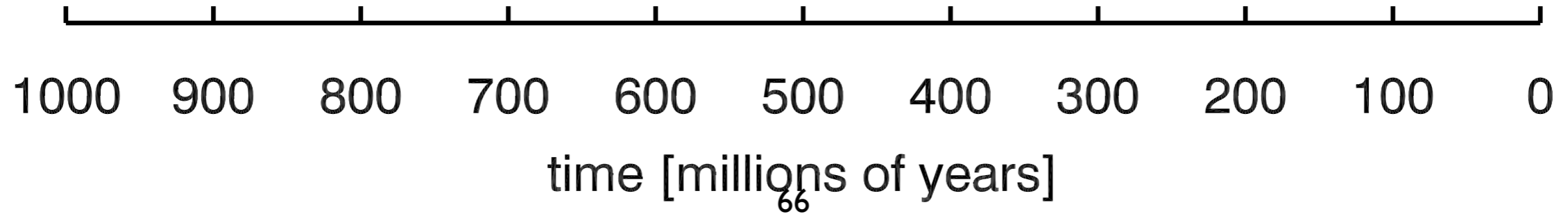
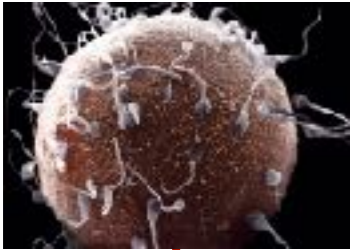




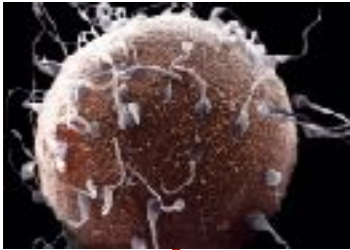
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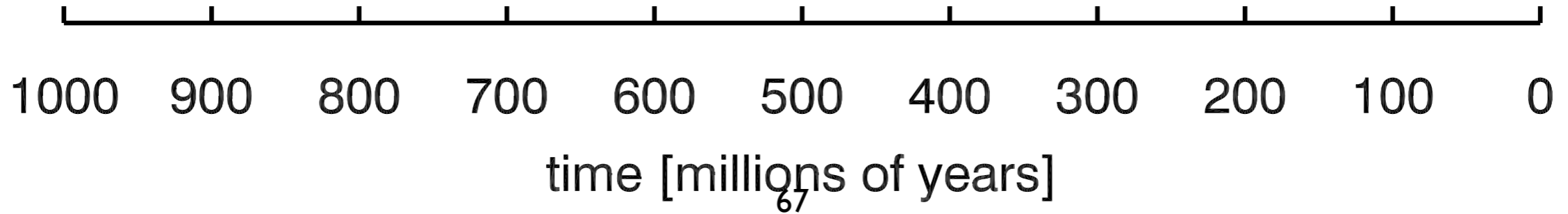
# Biological Time



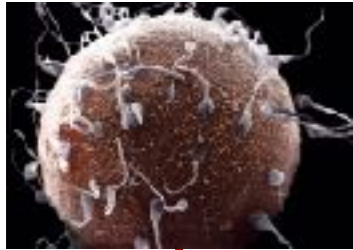
# Biological Time



Sexual reproduction begins  
~1 billion years ago



# Biological Time



**Sexual reproduction begins  
~1 billion years ago**

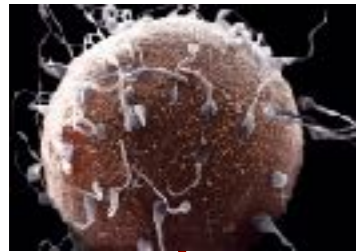


**First multi-celled animals  
~900 million years ago**

1000 900 800 700 600 500 400 300 200 100 0

time [millions of years]

# Biological Time



**Sexual reproduction begins**  
**~1 billion years ago**



**First multi-celled animals**  
**~900 million years ago**

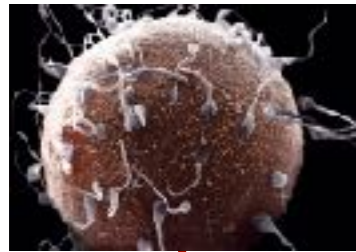


**First plants on shore**  
**~700 million years ago**

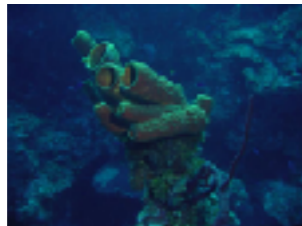
1000 900 800 700 600 500 400 300 200 100 0

time [millions of years]

# Biological Time



**Sexual reproduction begins**  
**~1 billion years ago**



**First multi-celled animals**  
**~900 million years ago**



**First plants on shore**  
**~700 million years ago**

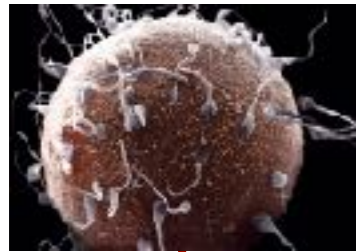


**First vertebrates (Fish)**  
**~550 million years ago**

1000 900 800 700 600 500 400 300 200 100 0

time [millions of years]

# Biological Time



**Sexual reproduction begins**  
**~1 billion years ago**



**First multi-celled animals**  
**~900 million years ago**



**First plants on shore**  
**~700 million years ago**



**First vertebrates (Fish)**  
**~550 million years ago**

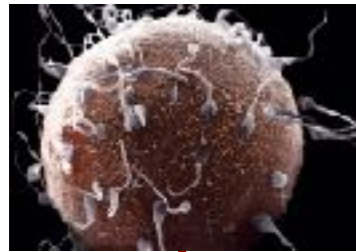


**Plants develop seed**  
**~360 million years ago**

1000 900 800 700 600 500 400 300 200 100 0

time [millions of years]

# Biological Time



**Sexual reproduction begins**  
**~1 billion years ago**



**First multi-celled animals**  
**~900 million years ago**

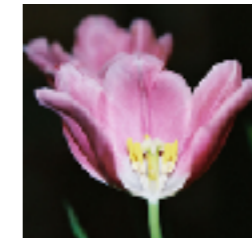


**First plants on shore**  
**~700 million years ago**



**First vertebrates (Fish)**  
**~550 million years ago**

**Plants develop seed**  
**~360 million years ago**



**Flowering plants develop**  
**~200 million years ago**

1000 900 800 700 600 500 400 300 200 100 0

time [millions of years]



# Biological Time



**Sexual reproduction begins**  
**~1 billion years ago**



**First multi-celled animals**  
**~900 million years ago**



**First plants on shore**  
**~700 million years ago**



**First vertebrates (Fish)**  
**~550 million years ago**



**Plants develop seed**  
**~360 million years ago**



**Flowering plants develop**  
**~200 million years ago**



**Dinosaurs**  
**230 – 65 Myr ago**



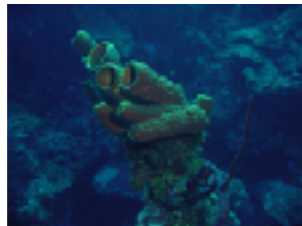
1000 900 800 700 600 500 400 300 200 100 0

time [millions of years]

# Biological Time



**Sexual reproduction begins  
~1 billion years ago**



**First multi-celled animals  
~900 million years ago**



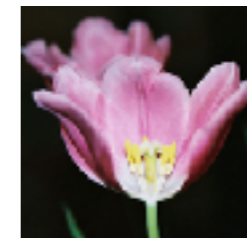
**First plants on shore  
~700 million years ago**



**First vertebrates (Fish)  
~550 million years ago**



**Plants develop seed  
~360 million years ago**



**Flowering plants develop  
~200 million years ago**



**Dinosaurs  
230 – 65 Myr ago**



**Mammals**

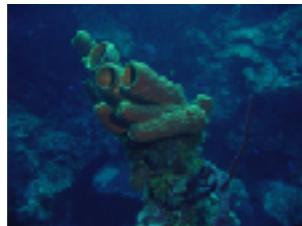
1000 900 800 700 600 500 400 300 200 100 0

time [millions of years]

# Biological Time



**Sexual reproduction begins  
~1 billion years ago**



**First multi-celled animals  
~900 million years ago**



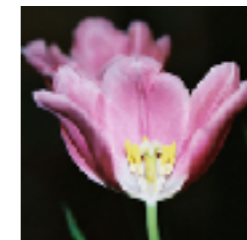
**First plants on shore  
~700 million years ago**



**First vertebrates (Fish)  
~550 million years ago**



**Plants develop seed  
~360 million years ago**



**Flowering plants develop  
~200 million years ago**



**Dinosaurs  
230 – 65 Myr ago**



**Mammals**



**Hominids ~6 Myr  
Stand on 2 feet ~3.5 Myr**

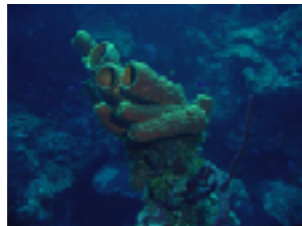
1000 900 800 700 600 500 400 300 200 100 0

time [millions of years]

# Biological Time



**Sexual reproduction begins  
~1 billion years ago**



**First multi-celled animals  
~900 million years ago**



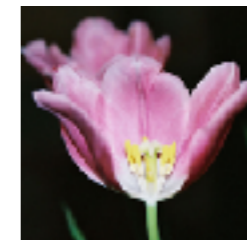
**First plants on shore  
~700 million years ago**



**First vertebrates (Fish)  
~550 million years ago**



**Plants develop seed  
~360 million years ago**



**Flowering plants develop  
~200 million years ago**



**Dinosaurs  
230 – 65 Myr ago**



**Mammals**



**Hominids ~6 Myr  
Stand on 2 feet ~3.5 Myr**

1000 900 800 700 600 500 400 300 200 100 0

time [millions of years]

# Human Species Time

writing  
~ 5,000  
years ago  
...and then...  
civilization

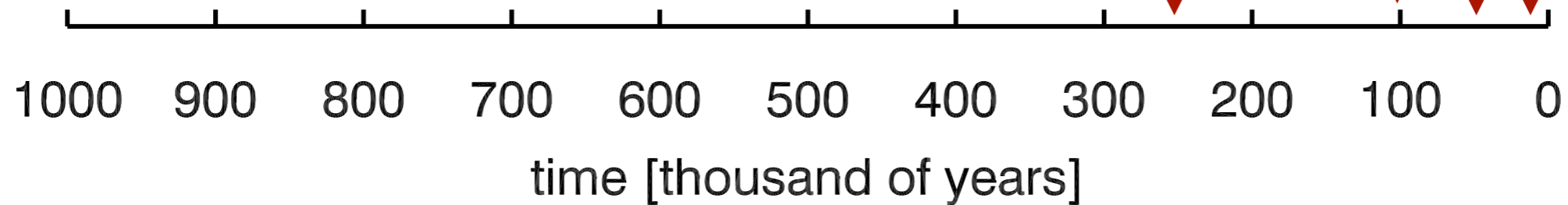
agriculture  
~ 10,000  
years ago

Counting  
~ 50,000 years ago

Humans leave Africa  
~ 100,000 years ago

Homo sapiens  
~ 250,000 years ago

Stone Tools  
~ 1.8 Million years ago  
Homo Erectus



# The Future

