Astro 301/ Fall 2006

(50405)

Introduction to Astronomy

http://www.as.utexas.edu/~sj/a301-fa06

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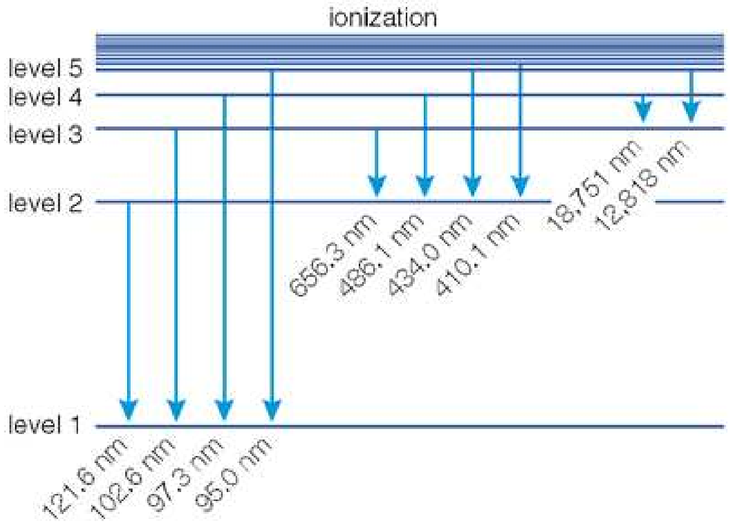
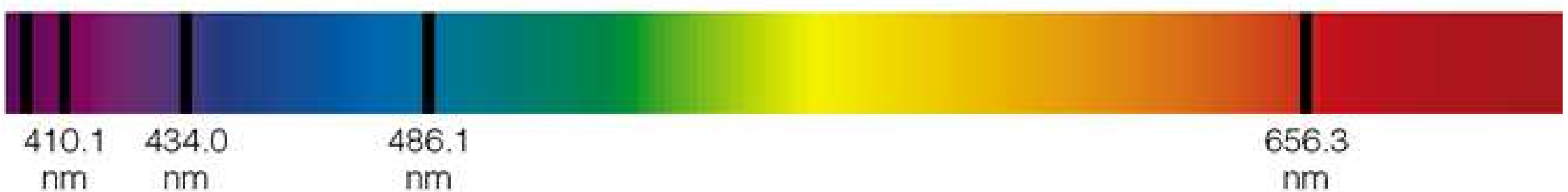
Lecture 23: Th Nov 30

Emission and Absorption Lines of Hydrogen



Emission lines from hot hydrogen gas



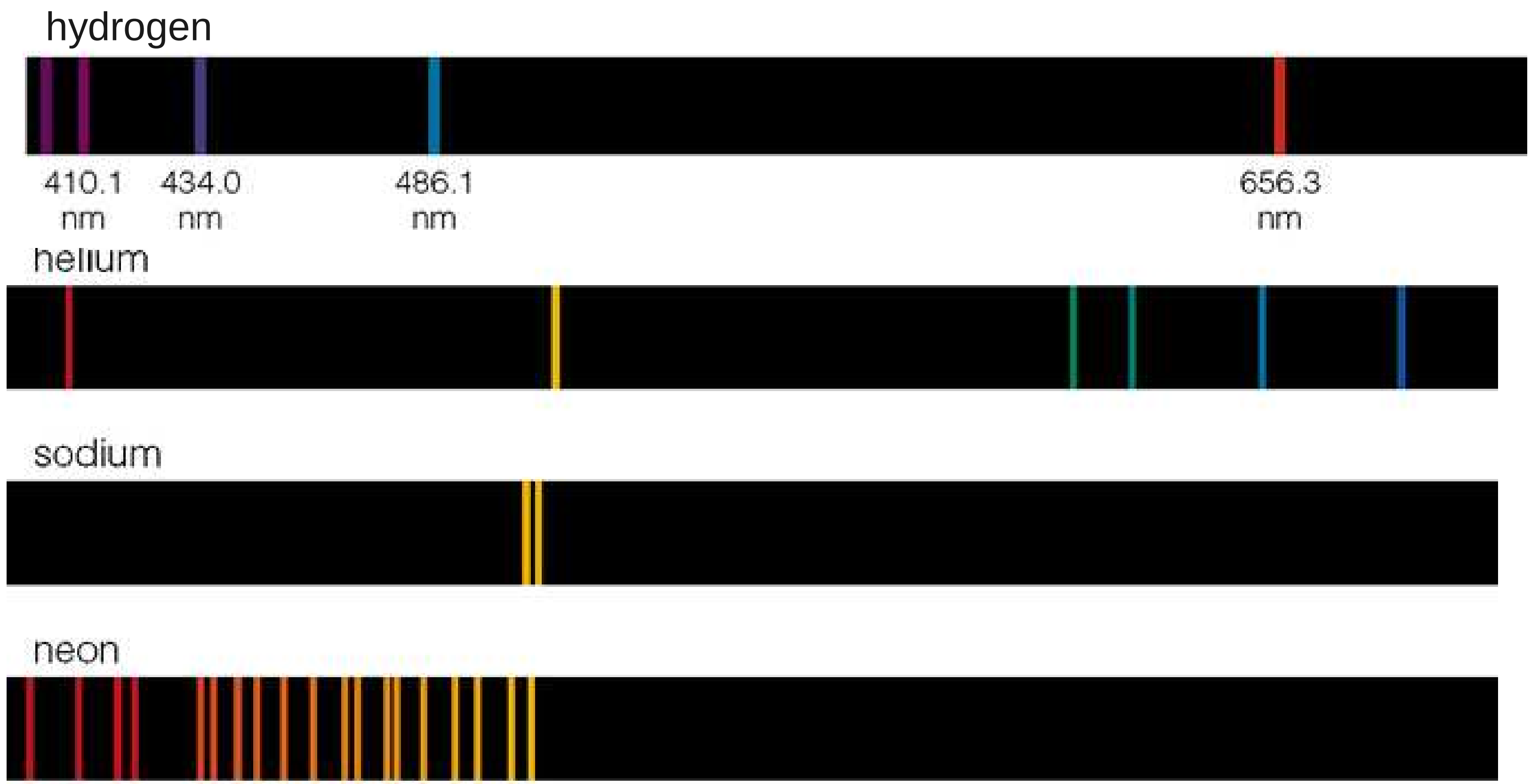
Absorption lines produced when continuum light (e.g., from a star) goes through cold hydrogen gas

Emission and Absorption Lines from Atoms

à In-class animation: “Production of Emission lines”

à In-class animation: “Production of absorption lines”

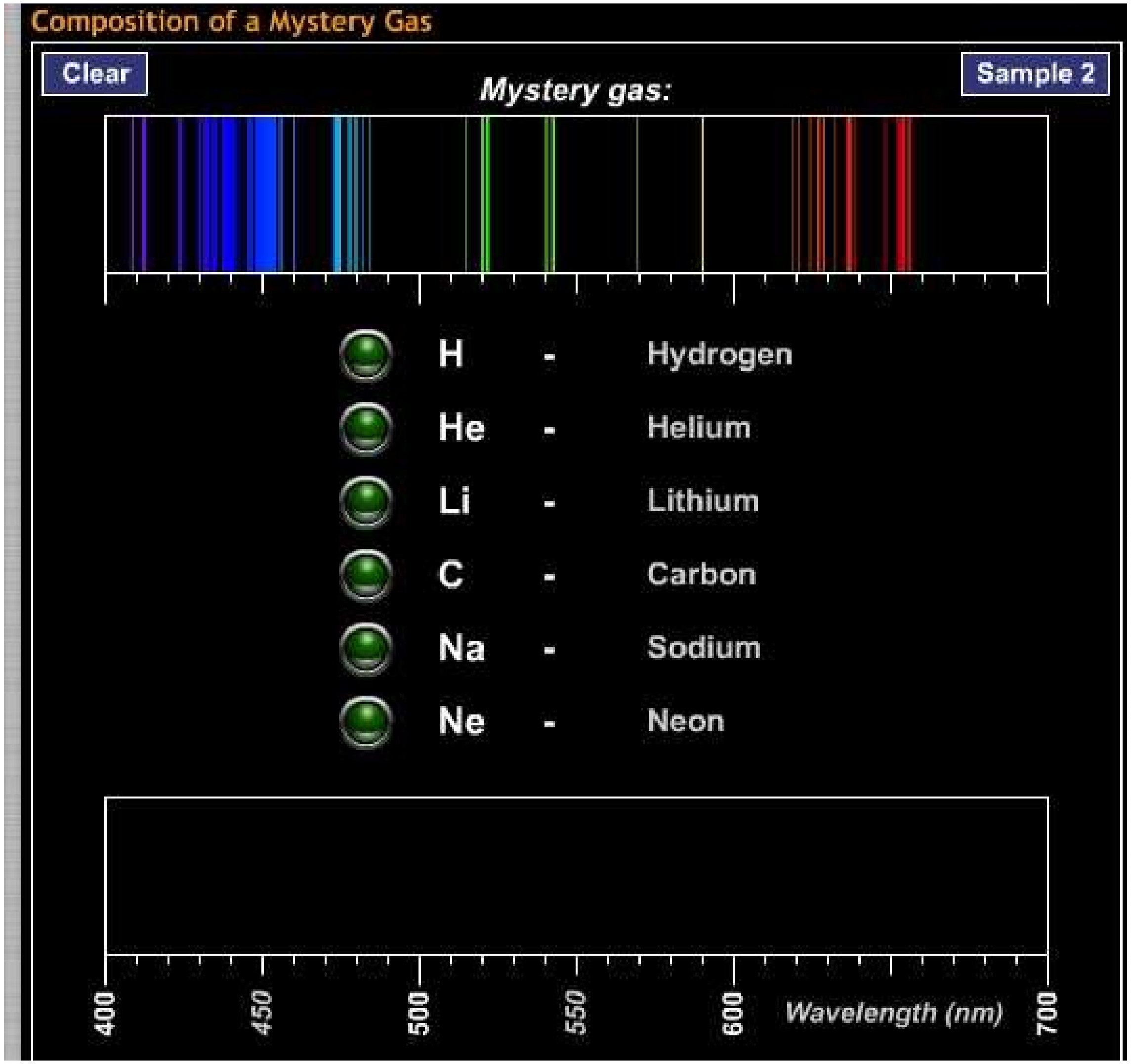
Each element produces a unique set of emission and absorption lines



Each chemical element has

- a unique set of energy levels (that differs from one element to another)
- will lead to unique set of electron transitions between these levels
- will lead to the emission or absorption of photons at a unique set of wavelengths
- will lead to emission lines or absorption lines at a unique set of wavelengths

à The emission spectrum of an element acts like a fingerprint / DNA of the atom



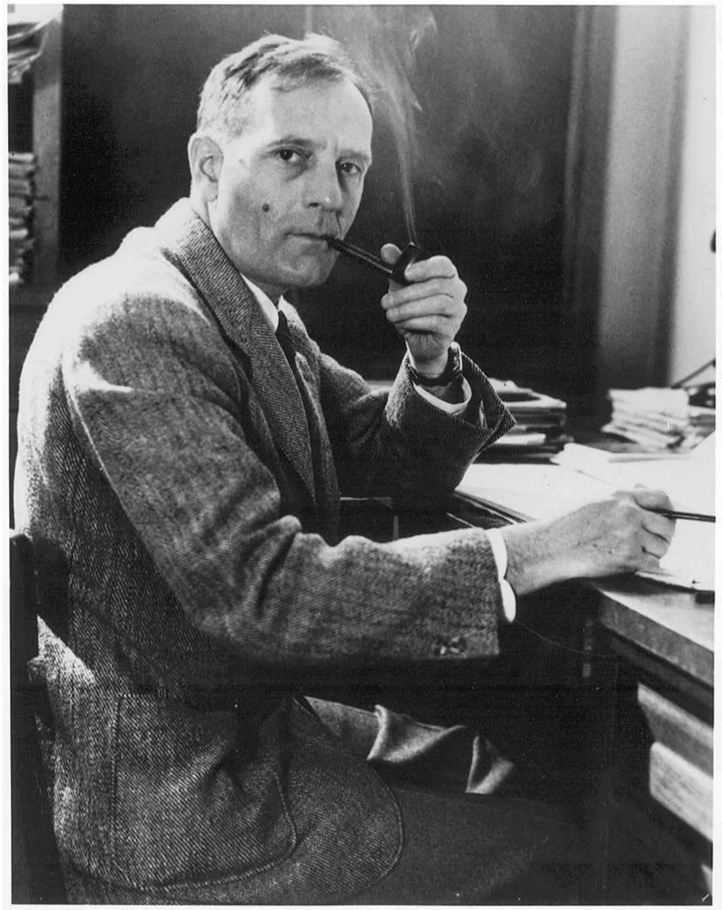
à In-class demo : Composition of Mystery gas

Expansion of the Universe

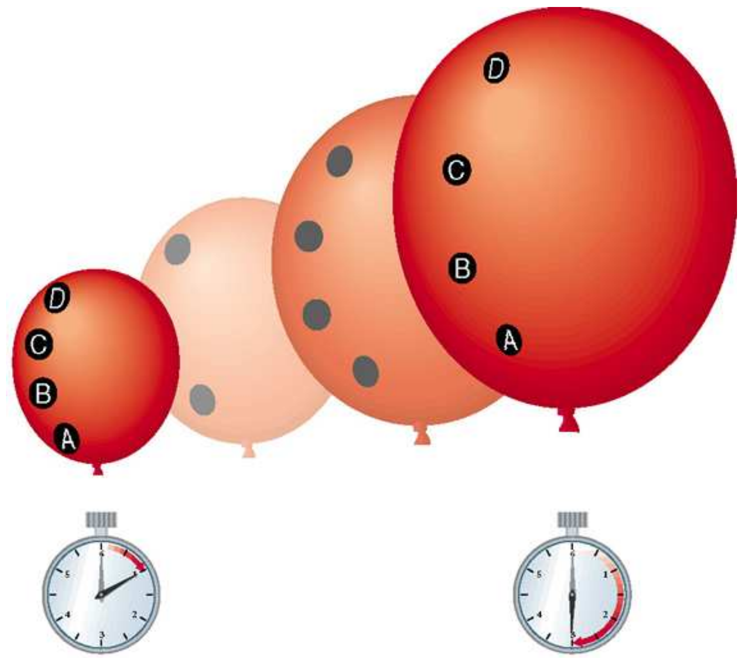
Edwin Hubble using the
100 inch at Mt Wilson

“At the last dim horizon, we search among ghostly errors of observations for landmarks that are scarcely more substantial. The search will continue. The urge is older than history. It is not satisfied and it will not be oppressed.’’

Motion of galaxies: Hubble's Law and the Expansion of the Universe



Edwin P. Hubble (1889-1953)



Hubble' law (1929) : galaxies separated by a large distance D recede from each other at speed v such that $v = H_0 \times D$

à Evidence that the Universe is expanding…. the basis of modern cosmology
à Einstein visited Hubble in 1931 to thank him for correcting his 'biggest blunder
à Hubble Space Telescope named after Hubble

What opposes and produces the expansion of the Universe ?

A mysterious force called Dark Energy is causing the Universe to expand, thereby making the space between galaxies increase

What force opposes dark energy?

The force of gravity between all objects that have mass (both visible matter and dark matter) tries to pull objects together, and tries to oppose the expansion of the Universe

Most of the matter in the Universe is dark matter and hence most of the force of gravity opposing the expansion of the Universe is from dark matter

The ultimate battle between expansion and gravity is a battle between

dark energy versus dark matter

Which is winning?

Dark energy…

The speed at which the Universe is expanding is getting higher and higher with time

We live in an accelerating Universe

Question: Hubble's law says that galaxies are moving away from each other.
But the nearby galaxy M31 is moving toward us (and not away from us) .Why?

à Because the force of gravity from the Milky Way and other galaxies in the local group is causing M31 to move toward us at high speed

à The expansion of the Universe is causing the space between us and M31 to increase at a much slower speed than the approach speed

à The net result is that M31 moves toward us

Redshift : Doppler redshift and Cosmological redshift

What is the redshift of a galaxy?

When we observe the emission lines of specific elements (e.g.., Hydrogen) in gas

a) in a laboratory, they have a certain wavelength λ_{rest} called the rest wavelength. The name "rest-wavelength" comes from the fact that the gas is nearly stationary or at rest with respect to us

b) in distant galaxies, their observed wavelength λ_{obs} is larger than their rest wavelength.

This redshift z of a galaxy is a measure of how much the observed wavelength is larger than the rest wavelength. It is defined by

$$z = (\text{Observed wavelength/ Rest wavelength}) - 1$$
$$= \lambda_{obs}/ \lambda_{rest} - 1$$

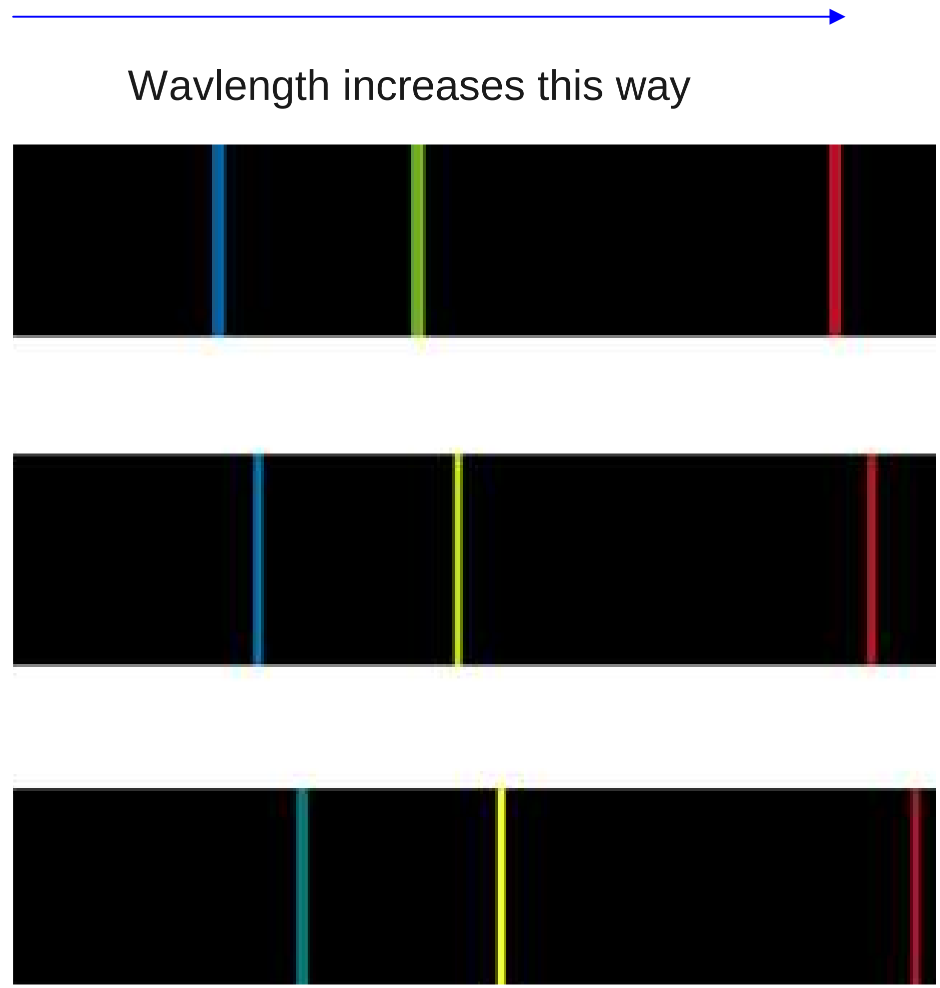
Example

Wavelength of H line from hydrogen gas in the lab = 6562.85×10^{-10} m

Wavelength of H line from distant galaxy = 13125.7×10^{-10} m

Redshift of distant galaxy = $(13125.7 \times 10^{-10}/6562.85 \times 10^{-10}) - 1 = 2 - 1 = 1$

Redshift



Lines measured in the laboratory have “rest-wavelength”

Lines measured in a moderately distant galaxy are slightly redshifted

Lines measured in a very distant galaxy are greatly redshifted

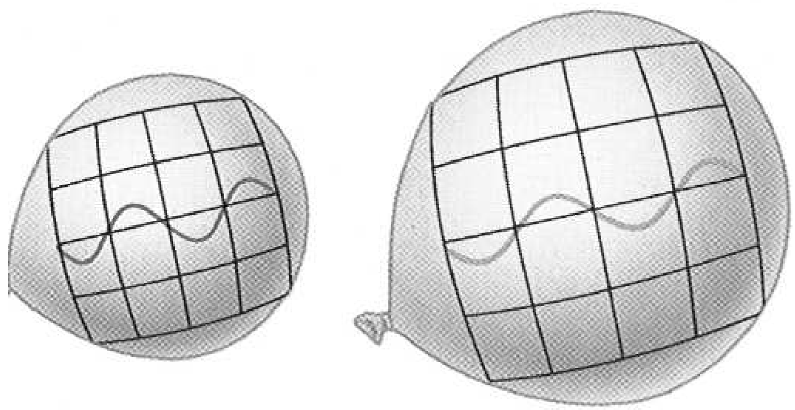
What produces the increase in wavelength (redshift) of the lines?

The redshfit of a galaxy is made up of two parts : cosmological redshift and Doppler redshfit. These are produced by two very different effects

1) Cosmological redshift

à The comological redshift is caused by the expansion of the **space** between the galaxy and us as a result of the expansion of the Universe.

à As photons travels from the galaxy to us, the expansion of space "stretches" the wavelength of the photon to larger values, hence redshifting it



à The more distant is the galaxy, the longer is the the travel time of the photon, the larger is the amount by which its wavelength is stretched

Hence more distant galaxies have higher cosmological redshift

à From the cosmological redshift of a galaxy, astronomers can derive

the size of the Universe when the photons that we receive now left the galaxy

the age of the Universe when the photons that we receive now left the galaxy

What produces the increase in wavelength (redshift) of the lines?

2) Doppler redshift

Dopper redshift is caused by the motion of the source through space away from the observer at relative speed v.

For distant galaxies, the Doppler redshift is insignificant compared to the cosmological redshift because

the local motion of galaxies due to the force of gravity of their neighbors is much smaller than the speed at which the space between us and the galaxies is expanding

For nearby galaxies, the Doppler redshift (or blueshift) is larger than the cosmological redshift

Studying the Formation and Evolution of Galaxies

* Today the Universe is 13.7 Gyr old and many massive mature galaxies (e.g., ellipticals, spirals) with well-defined components (e.g., disks, bars, bulges) are already in place.

* One of the main goals of astronomy is to answer questions such as :

- When and how did proto-galaxies – the precursors of galaxies-- first form?

- How did these proto-galaxies evolve and assemble over the last 13 Gyr into the mature galaxies that we see today?

- When and how did most of the stars that we see today in galaxies form ?

- When did barred spiral galaxies like our own Milky Way come into existence?

- What was the role played by dark matter?

How do we answer these questions?

Two ways to study how galaxy evolved with time

Approach 1

Analogy: Use the present-day photos and behavior of your grandparents to infer how they might have looked like earlier and how they evolved from birth to now

1) Use present –day galaxies in the local Universe as a test-bed to study processes (interaction, mergers, star formation, stellar evolution) that also occurred in the early Universe.
2) Extrapolate what we have learnt about these processes in the present-day Universe to the very different conditions that existed in the early Universe. e.g.,
   - à the young Universe was much denser than the present-day Universe: so galaxies were closer to each other and could interact more often
   - à proto-galaxies present in the early Universe were less massive than present-day spirals. They had large gas fractions (gas mass/total mass) than present day spirals

Approach 2

Analogy: Use actual photos of your grandparent taken in their childhood, teens, adult, and later years to understand how they evolved from birth to now

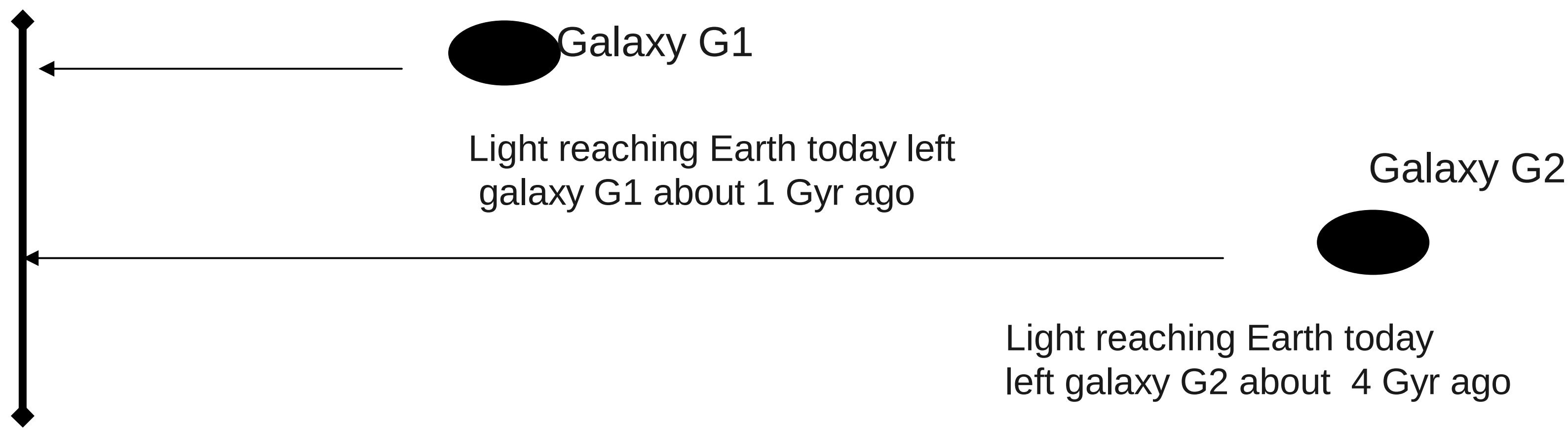
1) Look back in time to directly observe galaxies at different past epochs.
2) Use these observations as snapshots in time in order to charter their evolution

   HOW DO WE LOOK BACK IN TIME?

<u>Images of distant galaxies allow us to look back in time</u>

Light from distant galaxies take a long time to travel from the galaxy to Earth.

Example : Consider galaxies G1 and G2, which are located at distances of 1 billion light years and 4 billion light years



Light from galaxies G1 and G2 reaches the telescope on Earth today

à Image of G1 shows us how the galaxy looked like 1 billion years (1 Gyr) ago.
Lookback time of galaxy G1 is 1 Gyr.
The age of the Universe was then = Age today – Lookback time = 13.7 -1 = 12.7 Gyr

à Image of G2 shows us how the galaxy looked like 4 billion years (4 Gyr) ago.
Lookback time of galaxy G2 is 4 Gyr
Age of the Universe was then = Age today – Lookback time = 13.7 -4 = 9.7 Gyr

Images of distant galaxies allow us to look back in time

Suppose we observe a distant galaxy today with a telescope and make an image of the galaxy.

à the image we make today is made up of light that is reaching our telescope now, but actually LEFT the galaxy N years ago

à the image therefore shows us how the galaxy looked like N years ago

à the image therefore allows us to look back in time N years ago

Images of more distant galaxies allow us to look further back in time because light takes longer to travel from more distant galaxies to us.

What type of images allow us to detect very distant galaxies?

à Images with long exposures (called deep images) collect a lot of photons and are therefore able to detect objects that are faint and have low flux

à These faint objects with low flux include distant galaxies

Recall flux $f = L) / (4 \pi D^2)$ where L=luminosity, D=distance

Need deep long-exposure images to detect distant galaxies and look very far back in time.

Example

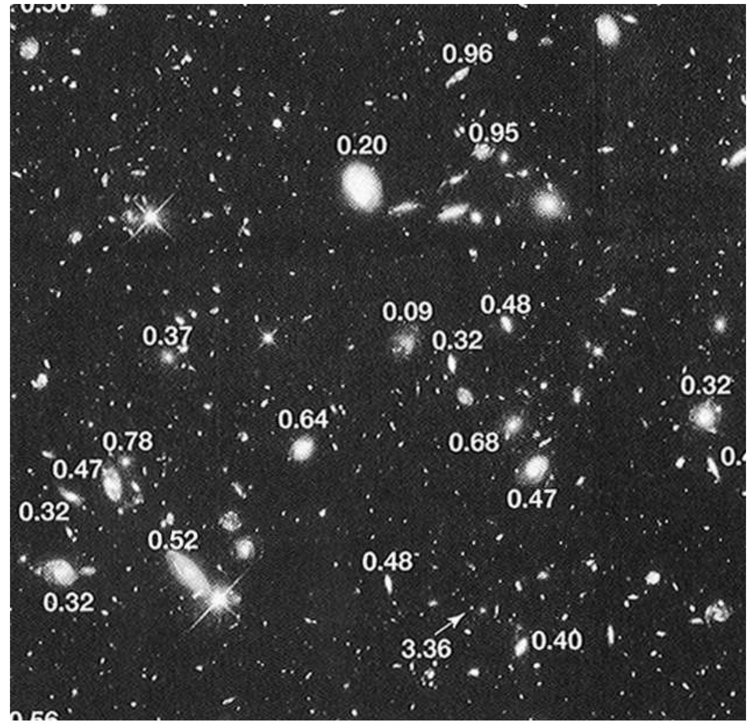
The Hubble Ultra Deep Field has an exposure time of 1 million seconds. It allows us to look back in time 13.0 billion years, when Universe was (13.7-13.0) = 0.7 Gyr ago

The GEMS survey has an exposure time of ~4320 seconds. It allows us to look back in time 9.0 billion years, when Universe was (13.7-9.0) = 4.7 Gyr ago

Important criteria for a powerful galaxy survey

What are the 4 criteria that a galaxy survey should satisfy in order to be effective, and why?

Large area
HST images
Deep exposures
Redshfit



Key Ingredients of Galaxy Surveys :Large Areas

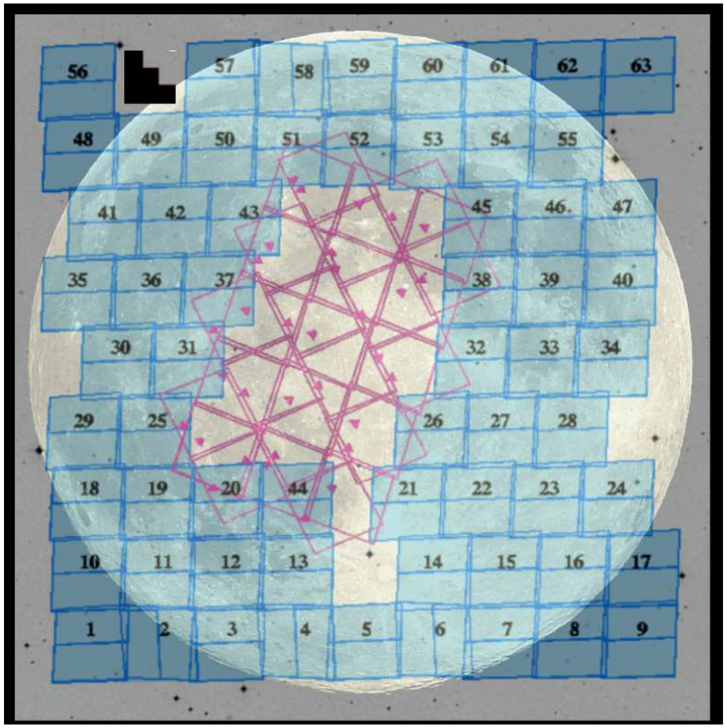
Why do we need to survey a large area?

à to map a large number of galaxies and get reliable statistics
à to map distinct different regions of the sky and capture the diversity of galaxies

Analogy: If you want survey the US population in order to RELIABLY predict the election results, then you must survey large regions all over the USA because
à   you need to survey a large no of people to get good statistics,
à   you need to survey different areas in order to capture the diversity of the population… else your resluts will not be representative

Example : Area covered by different surveys

- Hubble Deep Field (HDF) in1995
  = 7.5 arcmin squared
- Hubble Ultra Deep Field (HUDF) (2004)
  = 11 arcmin squared
- GEMS (2004)
  = 900 arcmin squared.



Key Ingredients of Galaxy Surveys :HST Images

Why do we need HST images rather than images from ground-based telescopes?
HST images

- are taken in space above the Earth's atmosphere
- are sharper than images from ground-based telescopes because they are not blurred by turbulence from the Earth's atmosphere
- allow us to separate different galaxies from each other in crowded fields
- allow us to resolve different components (bulge,disks, bars, spirals, tidal tails) of each galaxy

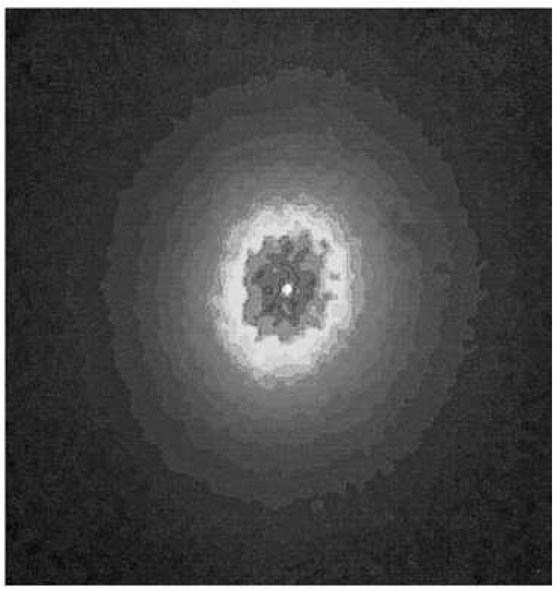


Image from ground telescope

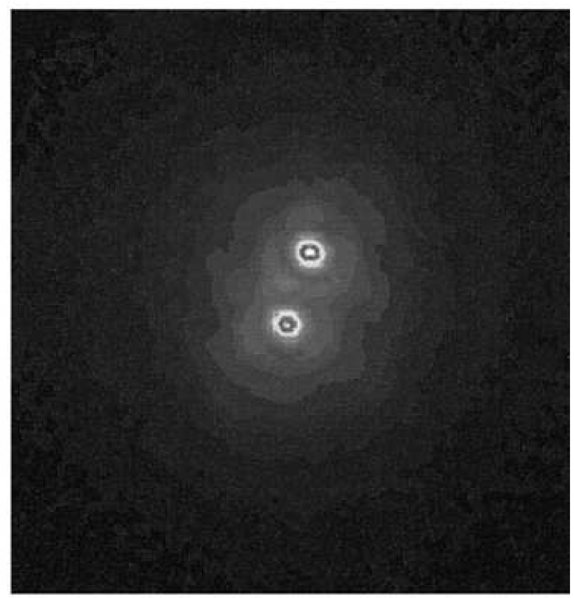


Image from Hubble Space telescope

Key Ingredients of Galaxy Surveys :Redshifts

Use ground telescopes to observe emission lines of different elements (e.g., H, Na Mg, etc) in each galaxy

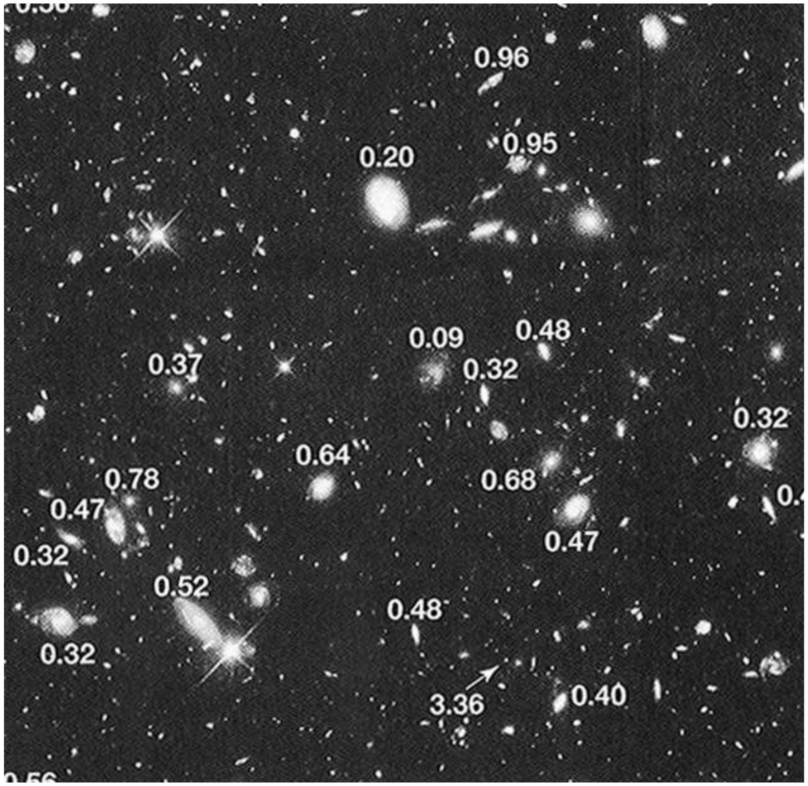
Calcuate the redshift z of each galaxy by comparing the observed wavelength of the lines in each galaxy to the rest wavelength of the same lines taken in the lab.

z = (Observed wavelength/ Rest wavelength) -1 = $\lambda_{obs}/\lambda_{rest} - 1$

In the image on RHS, the numbers next to each galaxy is the redshfit z of the galaxy

We need the redshfit z in order to assign a lookback time T_{back} to each galaxy in the image. Higher z correspond to larger lookback times and to younger galaxies

The lookback time allows us to calculate what was the age of the Universe at the time when the light left the galaxy

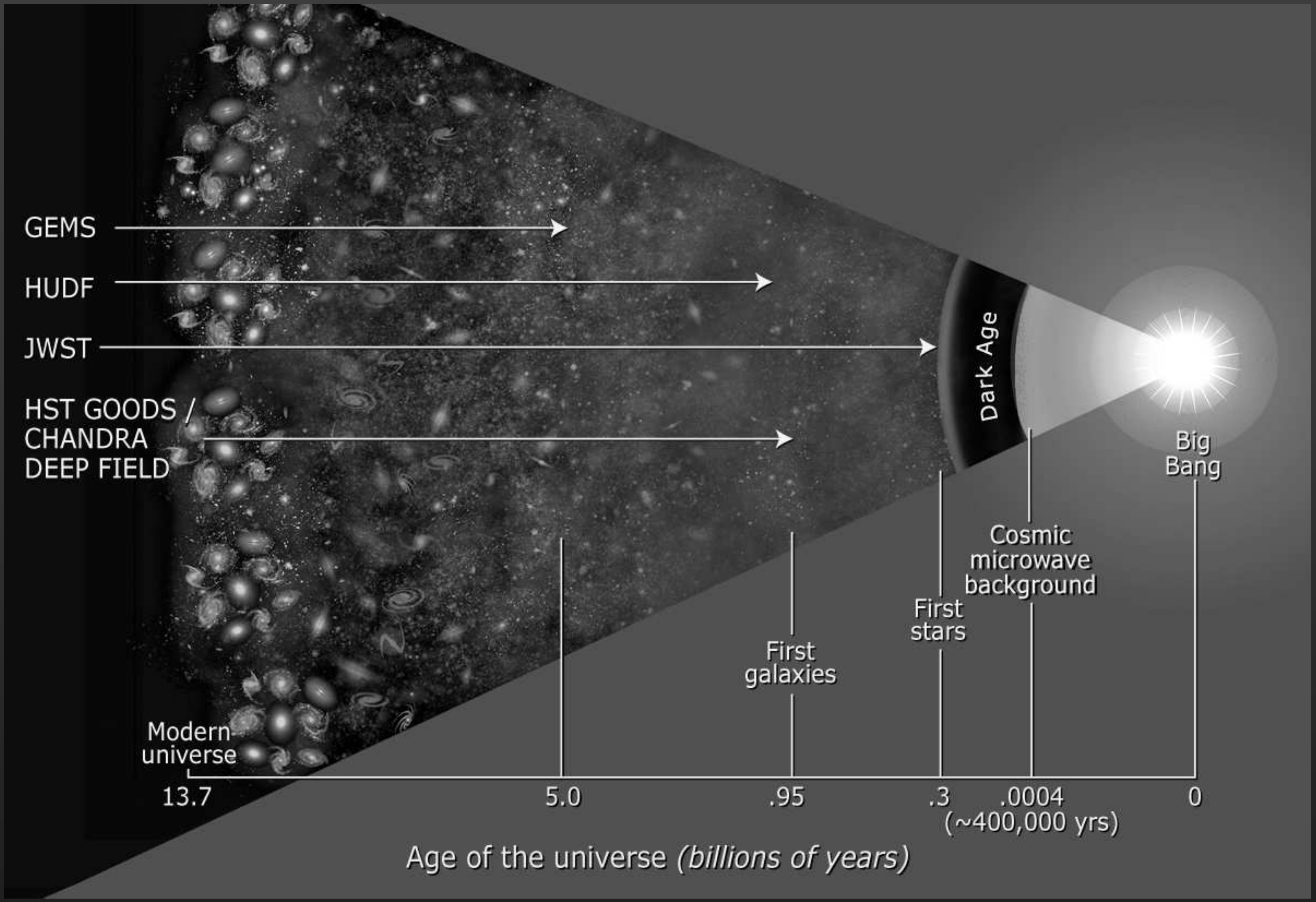


The GEMS survey

Comparsion of GEMS vs HUDF Galaxy Surveys

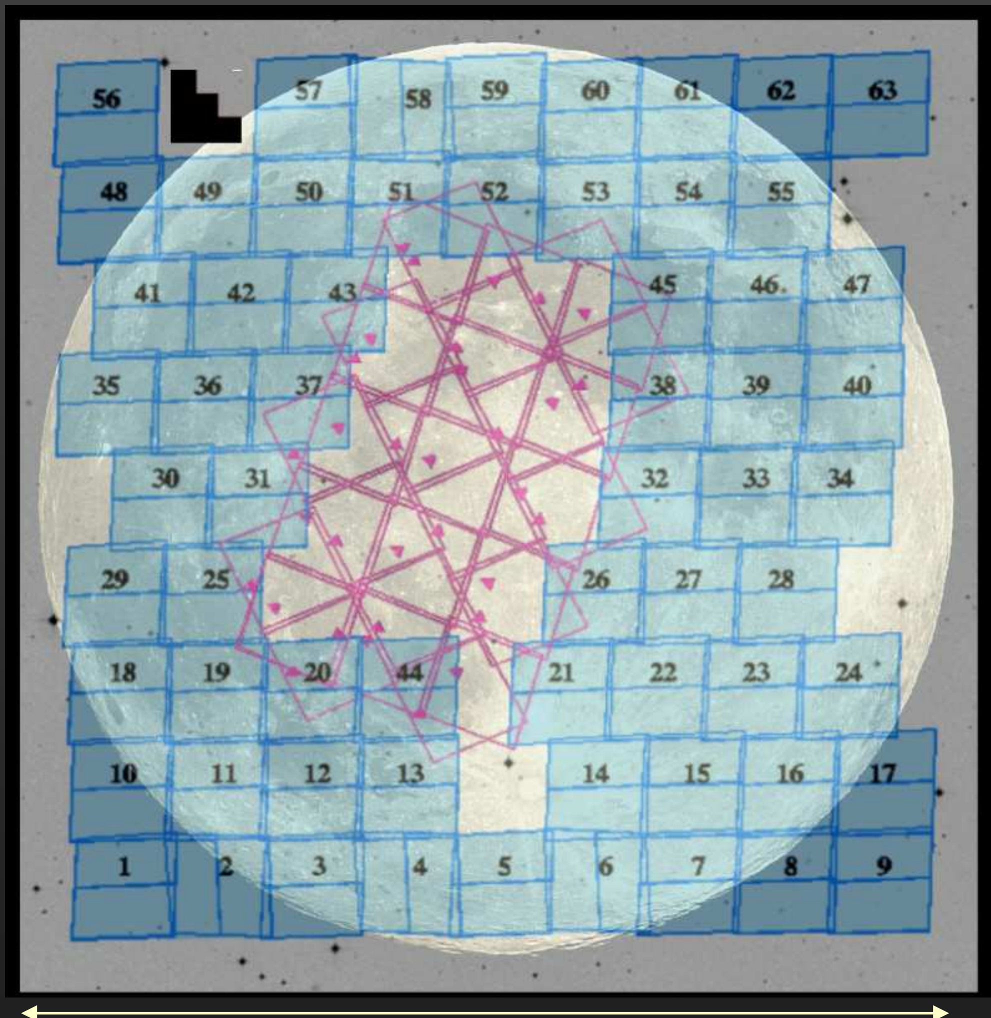
	GEMS survey	Hubble Ultra Deep field (HUDF)
Description	Largest-area survey conducted with Hubble Space Telescope	Deepest optical survey of the Universe with the Hubble Space Telescope
Telescope Camera	Hubble Space Telescope Advanced Camera for Surveys	Hubble space Telescopes Advanced Camera for Surveys
Completed	In 2004	In 2004
Area covered	30'x30' = 900 arcminute square	3.3'x3.3' = 11 arcmin square
Exposure time	~4300 seconds exposure	1 million second exposure
Lookback times probed	2 Gyr to 9 Gyr	2 to 13 Gyr
Depth or maximum lookback time	9 Gyr	13 Gyr
Youngest Age of Universe probed	13.7 - 9.0 = 4.7 Gyr	13.7-13.0 = 0.7 Gyr

Probing Early Cosmic Epochs with GEMS and HUDF



GEMS surveys galaxies out to lookback times of 9 Gyr, when Univ was 4.7 Gyr old
HUDF surveys galaxies out to lookback times of 13 Gyr , when Univ was 0.7 Gyr old

The GEMS survey



30’

GEMS is largest-area imaging survey conducted using 2 filters on the ACS camera aboard HST

GEMS survey area

= 77 ACS pointings patched together

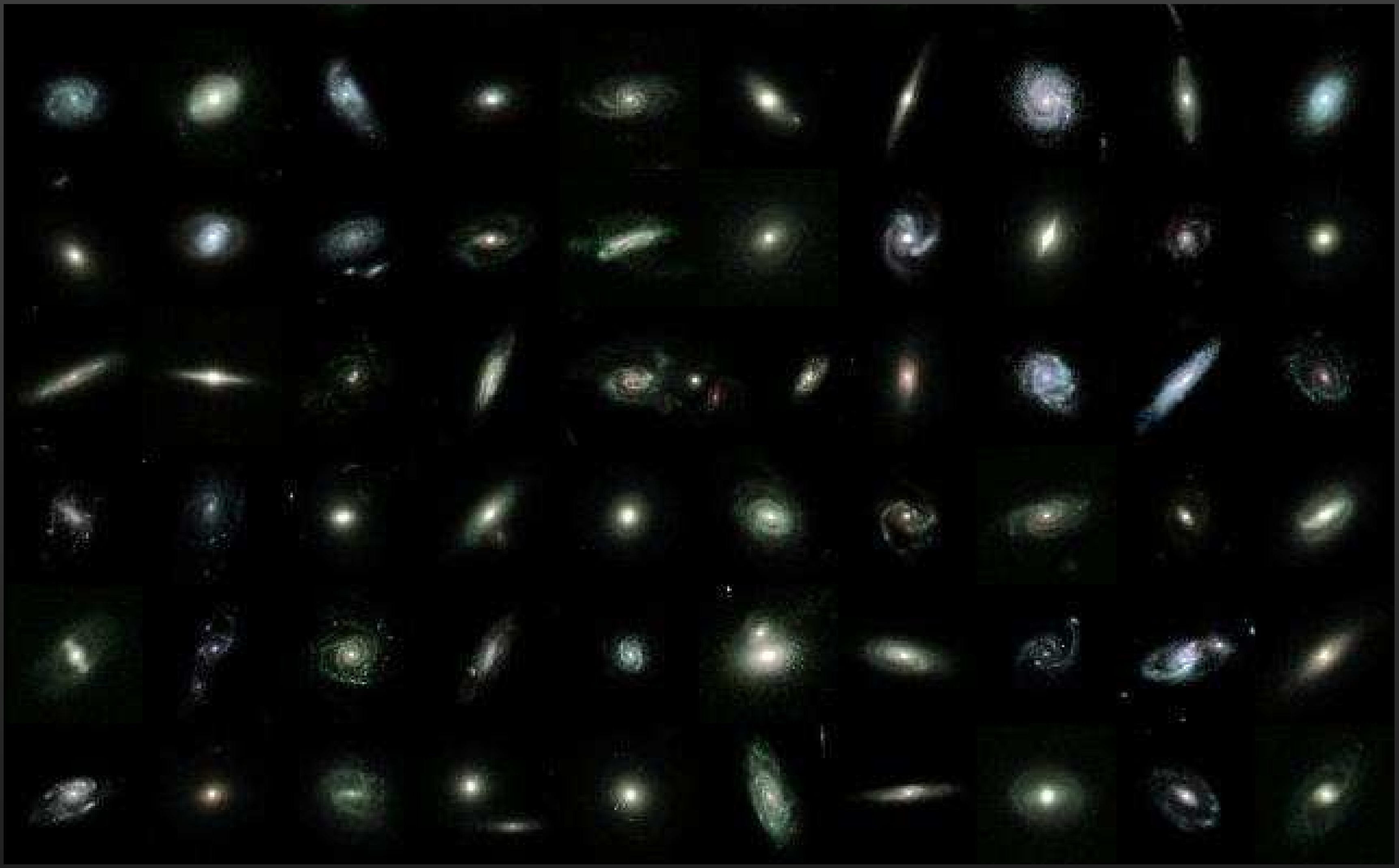
= 30’x30’= size of full moon on sky

= 120 x area of Hubble Deep Field (HDF) conducted with WFPC2 in 1995

= 72 x area of Hubble Ultra Deep Field (HUDF)

GEMS also has galaxy spectra which provide accurate redshifts for ~9000 galaxies. The redshifts are used to derive the lookback times, which lie in the range 2 to 9 Gyr

GEMS results



Provides family album of how galaxies looked like in their youth ('thirties')
Shows diverse galaxies were in place 9 Gyr ago, when Universe was only 30% of its present age!

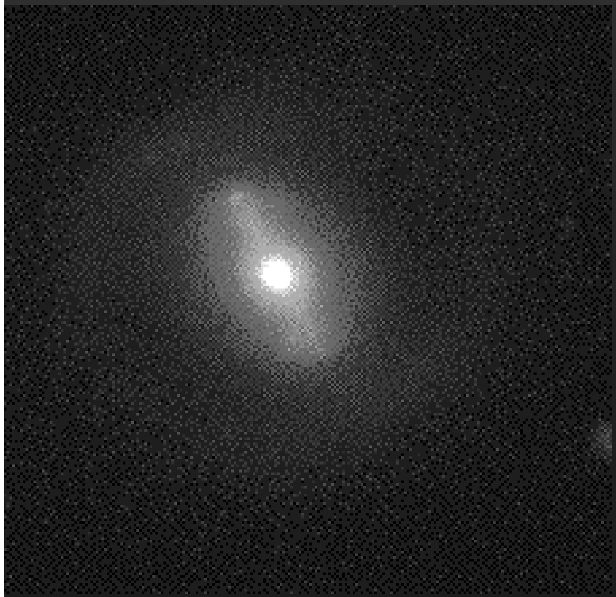
GEMS results

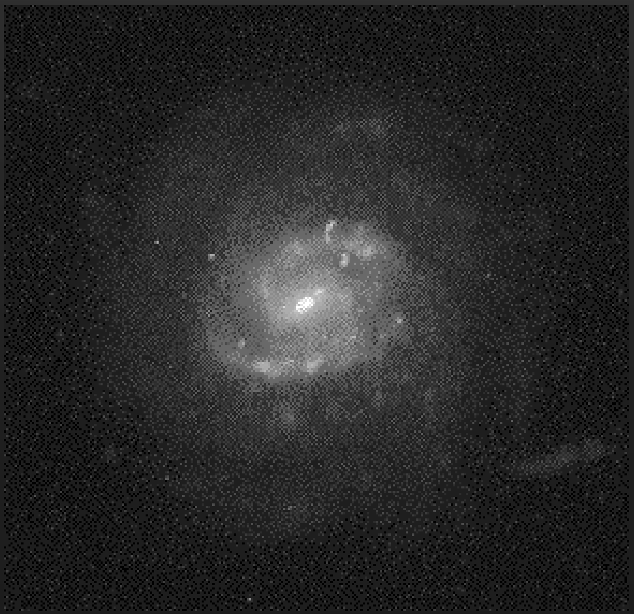
Early studies (1999) based on the HDF survey claimed that barred spirals similar to our Milky Way were ~ absent 9 Gyr ago and only formed very recently. This claim contradicted our best models of how barred spirals form !

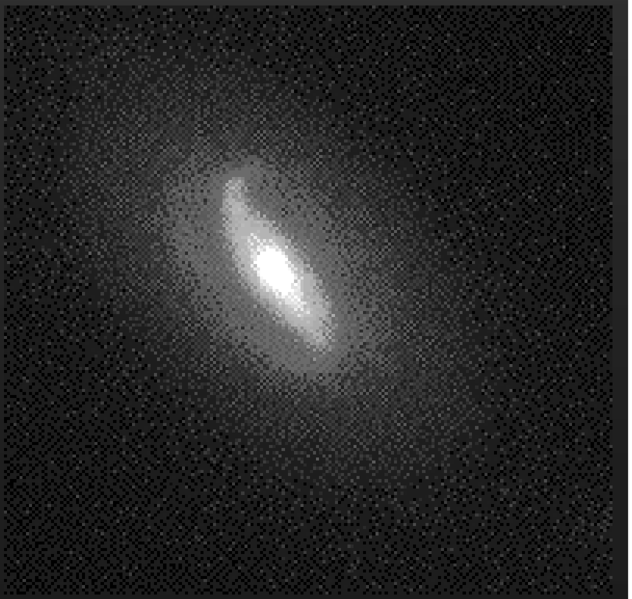
GEMS result (Jogee and GEMS team, 2004, The Astrophysical Journal)

à We conclusively demonstrated that barred spiral galaxies similar to our Milky Way are abundant at lookback times of 5 to 8 Gyr

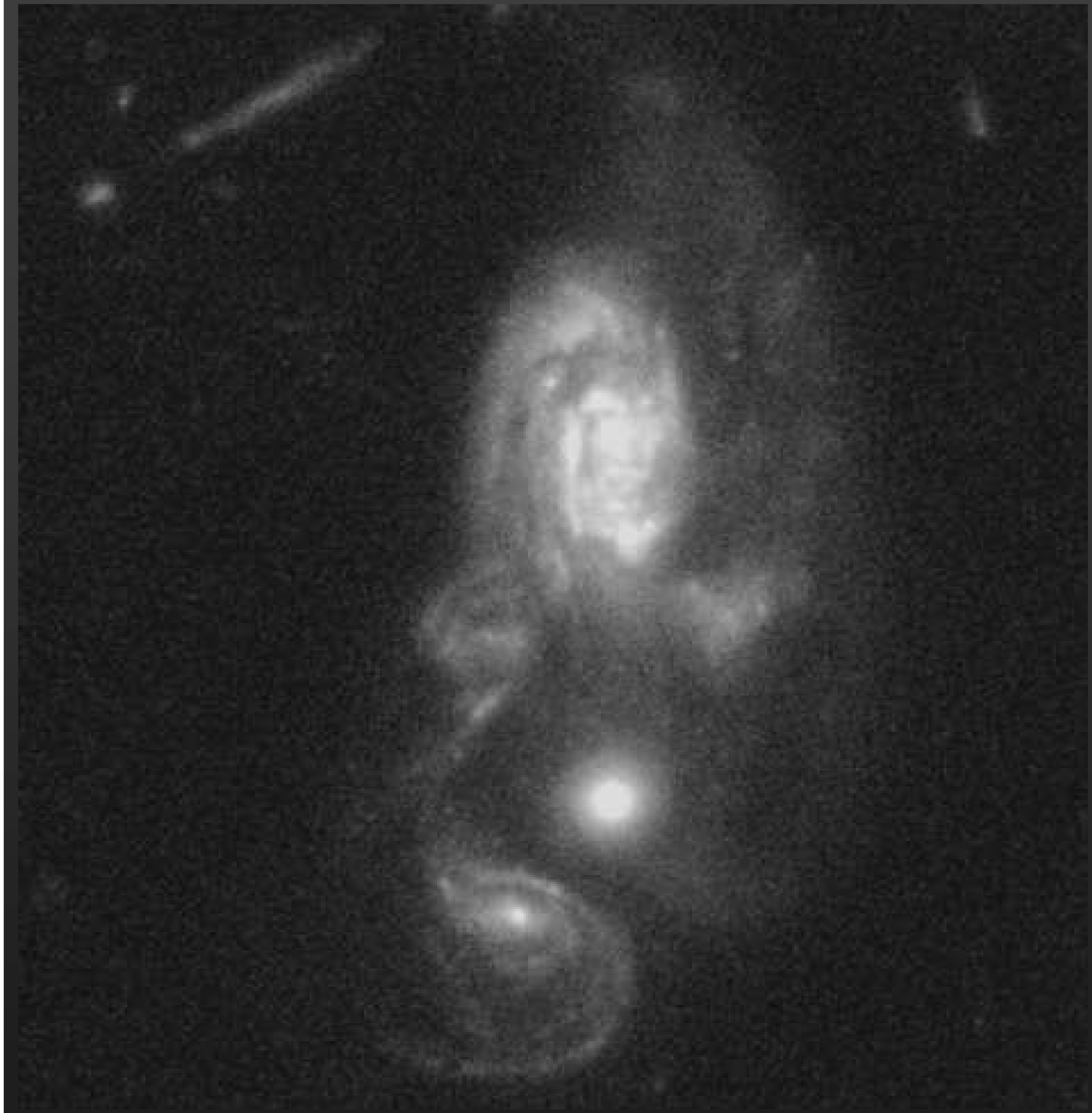
à We showed that bars are long-lived and strongly influence the dark matter







GEMS results



Interacting galaxies in GEMS

Over last 9 billion years ,

à The Universe transitions from a violent evolution to a more quiescent evolution

à the frequency of major mergers drops. Galaxies, instead, mainly undergo minor mergers and keep growing in mass slowly.

à HALF of the stars in elliptical galaxies are built over his period

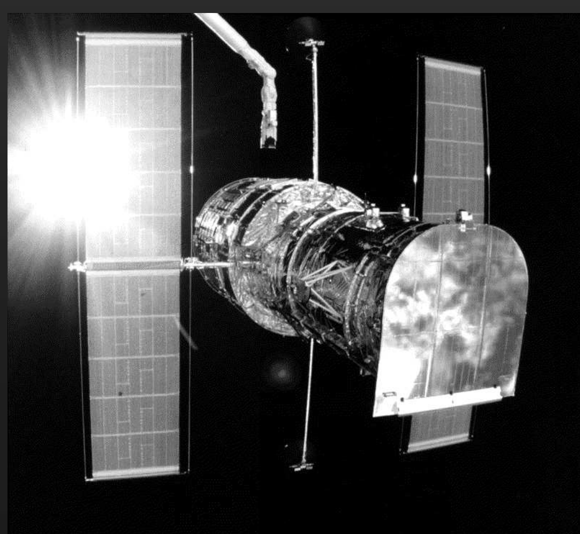
The HUDF survey

The Hubble Ultra Deep Field (HUDF) Survey in 2004

HUDF is ***the deepest visible-light image of the Universe***.

In 2004, the HUDF team proposed the HUDF legacy project and carried the technical planning and observations of the HUDF.

Exposures totaling a million s were taken with the Advanced camera for Surveys (ACS) on the Hubble Space Telescope

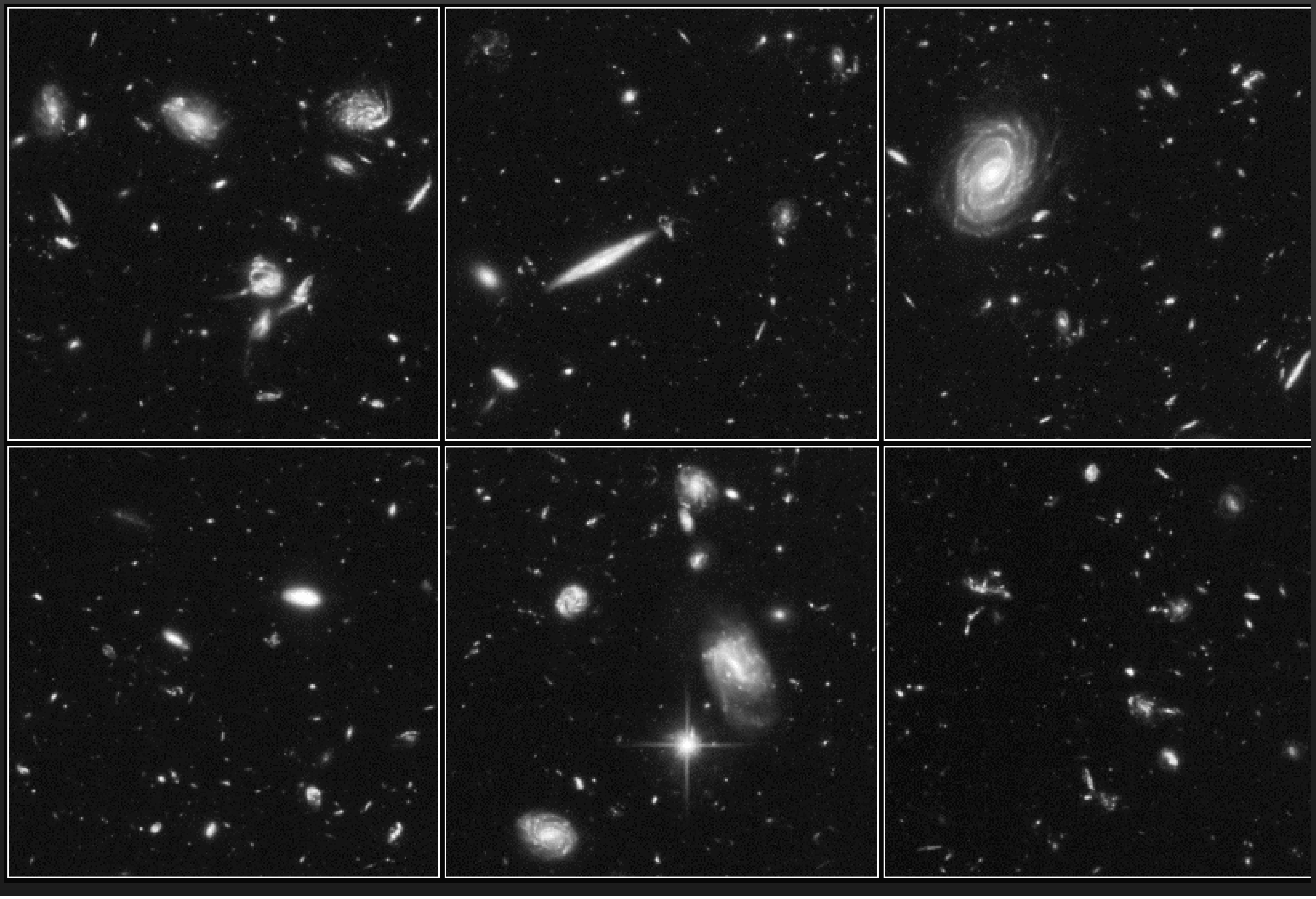


- Steve Beckwith*
- John Caldwell*
- Mark Clampin
- Michael Corbin
- Mark Dickinson
- Harry Ferguson*
- Andy Fruchter
- Richard Hook*
- Shardha Jogee
- Anton Koekemoer*
- Ray Lucas
- Sangeeta Malhotra
- Mauro Giavalisco
- Nino Panagia
- James Rhoads
- Massimo Stiavelli*
- Rachel Somerville
- Stefano Casertano
- Bruce Margon
- Chris Blades
- Massimo Robberto*
- Megan Sosey*
- Eddie Bergeron

HUDF team

The Hubble Ultra Deep Field (HUDF) Survey in 2004

HUDF allows us to look back about 12 Gyr in time….out to epochs when the Universe was merely 5% of its present age



Some HUDF results

At very early epochs, when the Universe was ~ 0.7 Gyr old (i.e 5% of its present age, corresponding to lookback times of 13 Gyr):

à first proto-galaxies, made of gas and dark matter were forming. They were similar to dwarf galaxies and much smaller than present-day spirals.

à the Universe was a violent place, dominated by very frequent mergers which assemble the proto-galaxies into larger blocks

As the Universe aged from 0.7 to 3 Gyr old (corresponding to lookback times of 10.7 Gyr):

à Mergers of proto-galaxies build bulges of spirals, disks of spirals, and some ellipticals. These galaxies are however not yet as massive as present-day systems and have to grow further by accretion and minor/major mergers