Astro 358/Spring 2012

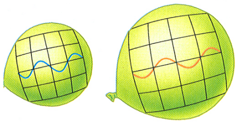
Discussion of Concepts relevant for Assignment on Next Generation Facilities

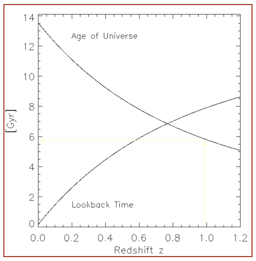
Mar 29, Apr 3, Apr 10

Cosmological redshift tells us age of Universe when light left the galaxy

Observed redshfit $z = \lambda_{obs}/\lambda_{rest} - 1$ = *function (Cosmological* $z_{\_cos}$, *Doppler* $z_{\_dop}$*)*

$1+ z_{\_cos}$ = *Size of Universe today/ Size of Univ when light left galaxy*
= *f (expansion rate of Universe, age of Universe)*

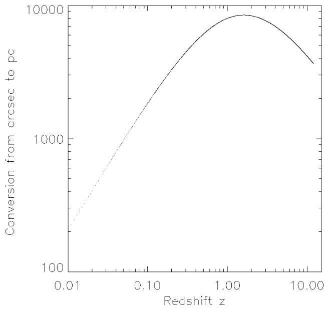




For distant galaxies can set $z = z_{\_cos}$ *and related z to age of Universe.*
e.g., at z= 1,
→ *age = 5.8 Gyr*
→ *lookback = 13.7 – age = 7.9 Gyr*

$(\Omega_m = 0.3, \Omega_\Lambda = 0.7, \Omega_k = 0, H0 = 70)$

Relationship between angular & physical scale of 1" varies with redshift



$(\Omega_m = 0.3, \Omega_\Lambda = 0.7, \Omega_k = 0, H0 = 70)$

1" corresponds to
~ 7000 pc at redshift z=1
~ 200 pc at redshift z=0.01

What angular resolution (or point spread function) do you need to resolve the bulge of a typical spiral galaxy at z=1? Assume the bulge has a radius of 1 kpc

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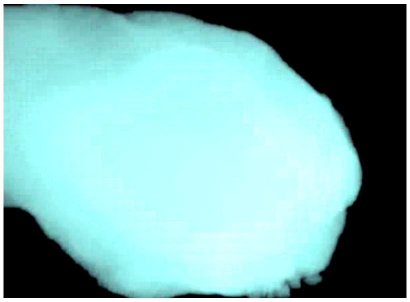
Current and Next-Generation Multi-wavelength Facilities :why do we need them?

Toy Simulation of How a Milky Way Type Galaxy is built



Courtesy:
Frank
Governato

Assembling a galaxy (made of gas, stars, dark matter) is a complex process involving gas accretion, mergers of galaxies and dark matter halo, and formation of new stars from cold gas. To understand that process we need **high resolution, multi-wavelength observations of many galaxies at different epochs**

Technical capabilities
(angular resolution, sensitivity, speed, etc)

Optical/IR telescopes: angular resolution and signal-to-noise

Ang. resolution: $\theta = \frac{1.22\lambda}{D}$

$\theta = \frac{2.1\times10^5\lambda}{D}$ arcseconds

Diffraction-limited angular resolution θ_{tel} of a single dish telescope

See in-class notes for discussion of points below

1) Angular resolution or PSF = = function of (θ_{atm}, θ_{pix}, $\theta_{electron}$, θ_{tel})
= function of atmosphere + telescope-instrument specs

2) Comparison of PSF for current and future facilities
- ground facilities, e.g., VLT, Keck, HET vs GMT
- space faciliities, e.g., HST/ACS, HST/NIC3 vs JWST

3) Signal to noise in CCD images
= function of (time t, source counts, photon noises, sky noise, detector noise, readout noise)

Radio Telescopes: Angular resolution of single dish radio telescope vs radio interferometer

Ang. resolution: $\theta = \frac{1.22\lambda}{D}$

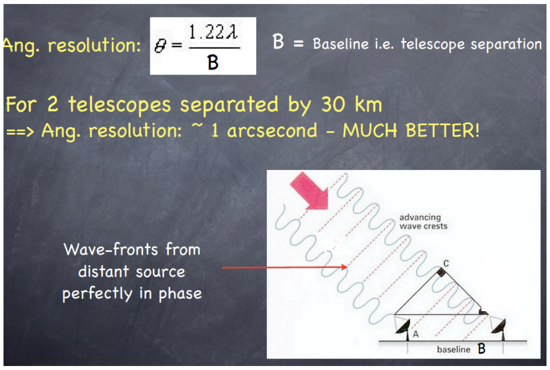
$\theta = \frac{2.1\times10^5\lambda}{D}$ arcseconds

Diffraction-limited angular resolution of a single dish telescope

Effelsberg 100-m @ 21cm:
440 arcsecs (8 arcmins)

Example of diffraction limited angular resolution for a single dish radio telescope of 100 m diameter

Radio Telescopes: Angular resolution of single dish radio telescope vs radio interferometer



Ang. resolution: $\theta = \frac{1.22\lambda}{B}$

B = Baseline i.e. telescope separation

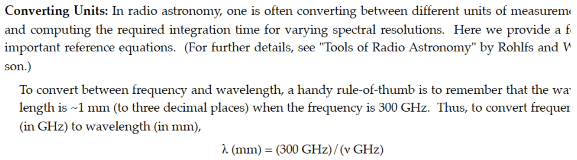
For 2 telescopes separated by 30 km

==> Ang. resolution: ~ 1 arcsecond - MUCH BETTER!

Wave-fronts from distant source perfectly in phase

Radio Observations: A few useful equations

Converting Units



Converting Units: In radio astronomy, one is often converting between different units of measurem and computing the required integration time for varying spectral resolutions. Here we provide a f important reference equations. (For further details, see "Tools of Radio Astronomy" by Rohlfs and W son.)

To convert between frequency and wavelength, a handy rule-of-thumb is to remember that the wa length is ~1 mm (to three decimal places) when the frequency is 300 GHz. Thus, to convert freque (in GHz) to wavelength (in mm),

λ (mm) = (300 GHz) / (ν GHz)

Spectral or velocity resolution

To achieve a particular velocity resolution Δv at a given observing frequency ν, requires a frequency resolution Δν of

$$\Delta\nu = \left(\frac{\Delta v}{c}\right)\nu.$$

For example, a 1 km/s resolution at 300 GHz would require a frequency resolution of 1 MHz. Conversely a channel spacing of 0.0153 MHz (Correlator mode 12, see table page 9) would correspond to a velocity spacing of 0.0153 km/s at 300 GHz, or 0.0051 km/s at 900 GHz.

Radio Observations: A few useful equations

Flux density and Brightness Temperature

The conversion from brightness temperature T to flux S_ν with synthesized beam solid angle Ω_s is

$$S_\nu = \frac{2\,\nu^2\,k\,T}{c^2}\Omega_s.$$

An alternate formulae that is often useful is

$$\left(\frac{T}{1K}\right) = \left(\frac{S_\nu}{1\ \mathrm{Jy\ beam}^{-1}}\right)\left[13.6\left(\frac{300\ \mathrm{GHz}}{\nu}\right)^2\left(\frac{1''}{\theta_{max}}\right)\left(\frac{1''}{\theta_{min}}\right)\right]$$

Noise in radio observations

Finally, the noise ΔS_ν, in an integration time Δt, varies with system temperature T_{sys}, frequency resolution Δν, number of antennas used N, diameter of the antennas D, and number of polarization measurements obtained n_p, in the following manner:

$$\Delta S \propto \frac{T_{sys}}{D^2\left[n_p\,N(N-1)\,\Delta\nu\,\Delta t\right]^{1/2}}\ \mathrm{W\,m^{-2}\,Hz^{-1}}.$$

Redshift-dependent systematic effects to consider when observing galaxies at high redshift

Redshift-dependent systematic effects

When observing galaxies at high redshift, need to consider redshift-dependent systematic effects, such as

1) Bandpass shift

2) Loss in spatial resolution (in pc) at a given angular resolution (aka `blurring')

3) Cosmological surface brightness dimming

Bandpass shift: a given filter traces light at different rest-frame wavelength in galaxies at different redshift

- A given filter (e.g., F606W filter with observed wavelength λ_{obs} of 5915 A) will trace light at different rest-frame wavelengths (λ_{rest}) in galaxies at different redshifts z . This effect is called bandpass shift

Example

F606W filter image of a galaxy at redshfit z traces rest-frame wavelength

$\lambda_{rest} = \lambda_{obs}/(1+z) = 5915\ A/(1+z)$

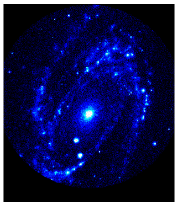
= rest-frame optical ($\lambda < 4000$ A) light if redshift $z < 0.5$

= trace rest-frame ultraviolet ($\lambda < 3000$ A) if redshift $z > 0.5$

→*Hence even if the 2 galaxies at different redshifts are identical, their F606W images can look very different as they are tracing light at different rest-frame wavelengths, which are dominated by stars of different temperature (Wien's law), mass and age. See figure on next page*

Below is an example of how the same galaxy looks different when one traces the rest-frame optical light versus the rest-frame UV light

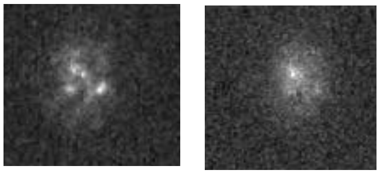
Rest-frame optical light
Is emitted by intermediate mass, long-lived stars that make up most of the stellar mass of an old galaxy



Rest-frame Ultraviolet light
Is emitted by massive short-lived stars that make up only a small fraction of the stellar mass of an old galaxy

Another Example of Bandpass Shift

Another example of bandpass shift is that a given galaxy at a given redshift z will look different when imaged with different filters, such as F06W and F850LP

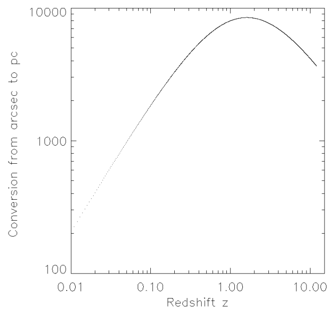


Same galaxy at z=0.8 observed in F606W (left) and in F850 LP (right)

F606W $\lambda_{rest} = 5915\ A/(1+z) = 3286\ A$ = *UV wavelengths*

F850LP $\lambda_{rest} = 9103\ A/(1+z) = 5057\ A$ = *optical wavelengths*

Loss in spatial resolution (in pc) at a given angular resolution



(Ω_m=0.3, Ω_Λ=0.7, Ω_k=0, H0=70)

1" corresponds to
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What angular resolution (or point spread function) do you need to resolve the bulge of a typical spiral galaxy at z=1? Assume the bulge has a radius of 1 kpc

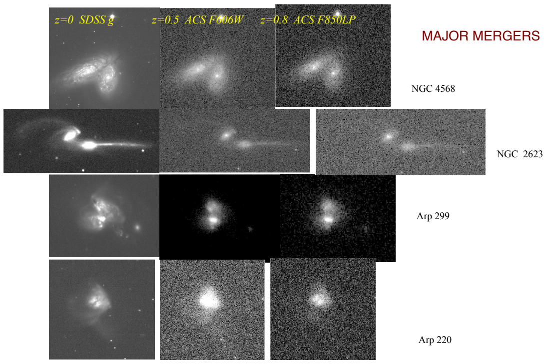
Cosmological surface brightness dimming

- See in class notes showing the bolometric SB of an object fall with redshift at rate of $(1+z)^{-4}$. This effect is a purely geometrical effect and is called cosmological SB dimming
- Hence when interpreting images of galaxies at high redshift, have to ask:
  Is the lack of low surface brightness features in the observed image of a galaxy due to the fact that these features are really absent in the galaxy
  OR
  is it due to the fact that geometrical cosmological effects dim the features out?

Examples of Cosmological SB dimming + loss of spatial resolution

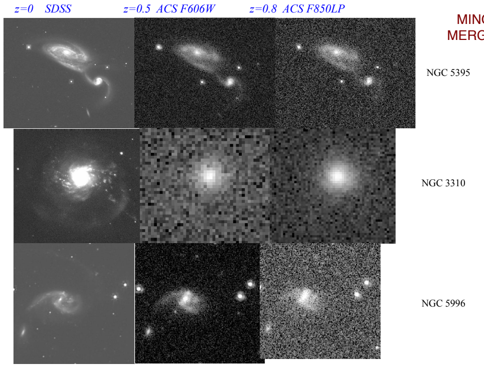
Artificially redshift local mergers out to z=0.5 and 0.8 and 'observe' with ACS
Courtesy: Jogee and Weinzirl (use FERENGI software by Barden et al. 2008)

MAJOR MERGERS



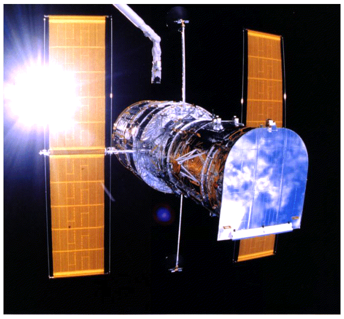
Examples of Cosmological SB dimming + loss of spatial resolution

MINOR MERGERS



Example of some large and deep optical surveys done with HST Advanced Camera for Surveys (ACS) from 2004-2009

Why do we need the Hubble Space Telescope (HST)



- *Launched in 1990*
- *Mirror diameter= 2.5-m*
- *Orbits 600 km above Earth*
- *Powered by solar batteries*
- *Instruments on board : uv, optical, infrared*

Advantage of HST vs. a ground-based telescope: BYPASS THE ATMOSPHERE

1) No blurring by Earths's atmosphere → image has high spatial resolution

2) Can observe UV photons without absorption by Earth's atmosphere

3) Can observe infrared emission without high background (glare) from sky

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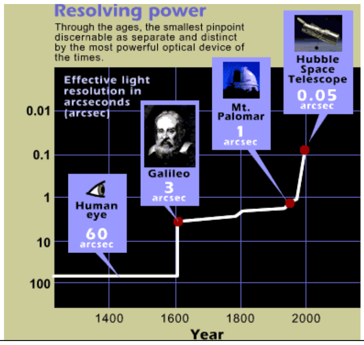
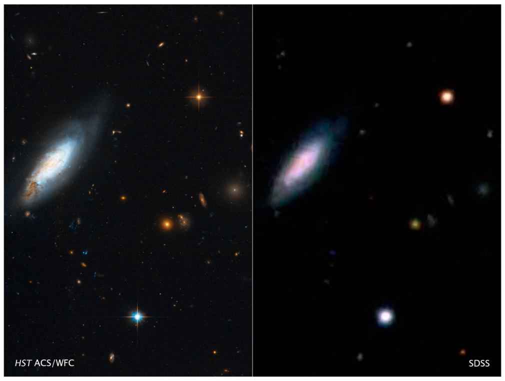
Optical Images from HST are sharper than ground image by a factor of over 30



HST vs Ground-based data for moderately distant galaxies in the Coma cluster



Courtesy: Z. Levay (STScI) NASA, ESA, Coma ACS Treasury Team

HST vs Ground-based data for very distant galaxies (redshift 0.2-1)

Combo-17 Ground image (tile 56)

Hubble ACS image from GEMS (tile 56)

Note the huge improvement in spatial resolution in going from the ground-based Combo-17 image (1.5") to space-based Hubble ACS image (0.1").

Galaxy Surveys with the Advanced Camera for Surveys (ACS) on Hubble Space Telescope as of 2003

SM3: Installing new gyroscopes and ACS aboard HST

Servicing Mission 3 (SM3) split into two parts.
→ SM3A in Dec 1999 via shuttle Discovery replace all 6 gyroscopes on HST
→ SM3B in Mar 2002 via shuttle Columbia : replace solar panels, install powerful ACS

The astronauts for SM3B

Advanced Camera for Surveys (ACS)

10 times more powerful than previous camera:

Much **larger field of view and sharper** images

Galaxy Surveys with ACS on Hubble

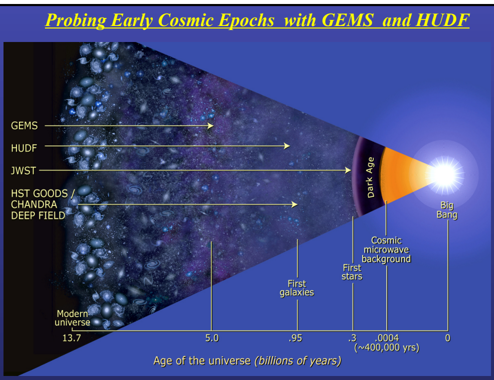
Early galaxy surveys,including the famous Hubble Deep Field (HDF) in 1996 used the old WFPC2 camera aboard HST . WFPC2 had a very small field of view

The Advanced Camera for Surveys (ACS) installed in 2002 is 10 times more powerful than WFPC2
- → has a larger field of view (60 times larger)
- → more sensitive
- → higher angular resolution

It has allowed several state-of-the art surveys of galaxy evolution in 2004
- → the GEMS survey : large area (30'x30'), moderare depth out to z~1
- → the COSMOS survey : large area (2 sq degree), moderare depth out to z~1
- → the GOODS survey : small area , large depth out to z~5
- → the HST Ultra Deep Field (HUDF) ; very small area, very deep out to z>6

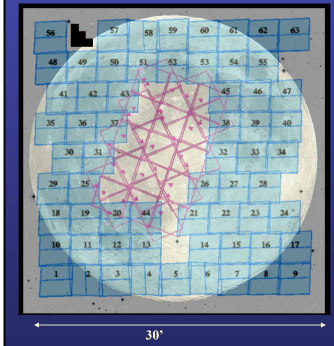
The GEMS Survey: Example of a shallow large-area survey of galaxies with HST

Probing Early Cosmic Epochs with GEMS and HUDF



GEMS surveys galaxies out to lookback times of 8 Gyr, when Univ was 5.7 Gyr old
HUDF surveys galaxies out to lookback times of 13 Gyr , when Univ was 0.7 Gyr old

The GEMS survey



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

GEMS survey area

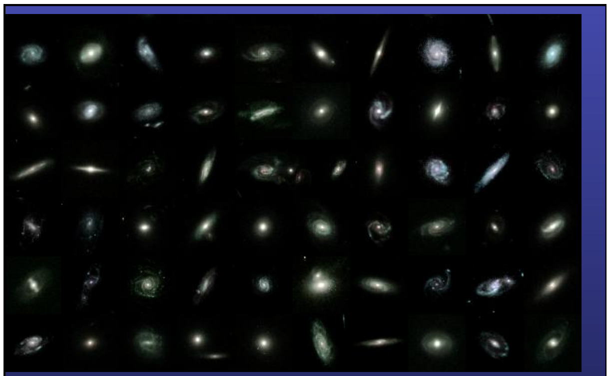
= 77 ACS pointings patched together

= 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



Example of normal 'non-merging' galaxies over z=0.7-1.0 (T_{back}~ 6-8 Gyr)

Example of interacting/merging galaxies at lookback =3 to 8 Gyr

(Jogee, Miller, Penne et al. & GEMS collaboration 2009, ApJ)

Example of interacting/merging galaxies at lookback =3 to 8 Gyr

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Galaxy and Cosmic Explorer Tool (GCET)

See in-class demo   = http://www.as.utexas.edu/gcet/

Surf the GEMS survey with your browser!

The Hubble Ultra Deep Field (HUDF) Survey: Example of a deep small-area survey of galaxies with HST

The Hubble Ultra Deep Field

HUDF = A public Legacy legacy survey done using the "Discretionary Time" of the Director (Steve Beckwith) of Space Telescope Science Institute

UDF/ACS Parameters
- ACS Pointing
- ACS Filters/Depth
- Phase II + Status

UDF Parallels
- ACS/HRC
- NICMOS
- WFPC2
- STIS

UDF GOODS Dataset

Data Release

Press Release

Talks/Posters

UDF Clearinghouse

- 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

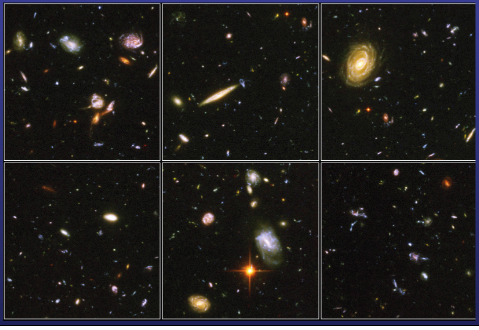
HUDF Home Team.

Science goals, technical calculations, planning strategy carried out by the HUDF Home Team.
http://www.stsci.edu/hst/udf/planning

410 HST orbits (or a total of 1 million s exposure time) used to observe a 3'x3' area using four filters (B V I z = F435W, F606W, F775W, F850LP)

HUDF survey: Looking back in time 13 billions years

The Hubble Ultra Deep Field (HUDF) is the deepest visible-light image of the Universe. It consists of a million s exposure taken with the ACS camera aboard HST in 2004 by the HUDF team. It probes lookback times of 13 Gyr , when Univ was a mere 0.7 Gyr old.

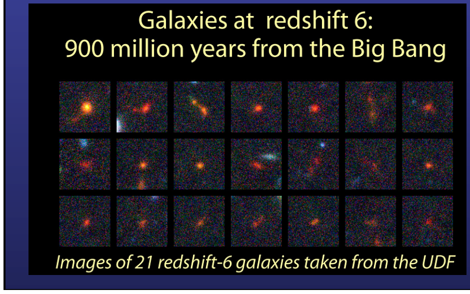


1) Galaxy surveys show early epochs of proto-galaxy evolution at z~6-7

At z~6-7 (when age of Universe~0.9 to 0.7 Gyr or 5% of its present age, corresponding to lookback times of 12.8 to 13.0 Gyr)

→ we see young proto-galaxies, made of (dark matter, gas, some stars)

→ the masses of these proto-galaxies are found to be similar to dwarf galaxies (mass~ 10^7-10^8 Msun) and much less massive than present-day spirals or E

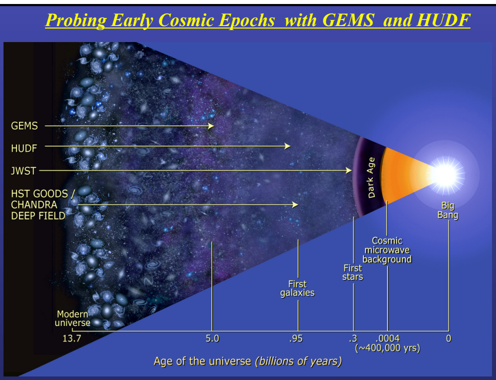


Galaxies at redshift 6:
900 million years from the Big Bang

Images of 21 redshift-6 galaxies taken from the UDF

Illingworth et al 2006

Probing Early Cosmic Epochs with GEMS and HUDF



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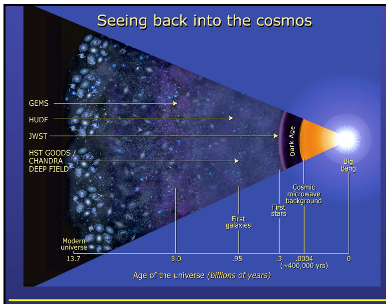
HUDF surveys galaxies out to lookback times of 13 Gyr , when Univ was 0.7 Gyr old



0.0	9	13.0	13.7	Lookback Time in Gyr
13.7 (100%)	4.7 (35%)	0.7 (5%)	0 (0%)	Age of Universe in Gyr and %

Today, mature galaxies on the Hubble sequence are in place

Over last 10 Gyr, from z=2 to 0
→ the mass and structures (disks, bars, bulges) of galaxies grow via accretion, secular evolution and mergers
→It appears that major mergers may not have played such a key role !

Chaotic period ~ 13.0 Gyr ago where first proto-galactic disks structures form and merge. The Universe is dominated by violent major mergers at early times.