Astro 358/Spring 2006

(48915)

Galaxies and the Universe

Instructor: Professor Shardha Jogee

TA: Ben Holder

Figures from Lecture 26: Tu Apr 25

The Hubble Ultra Deep Field (HUDF) survey

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.

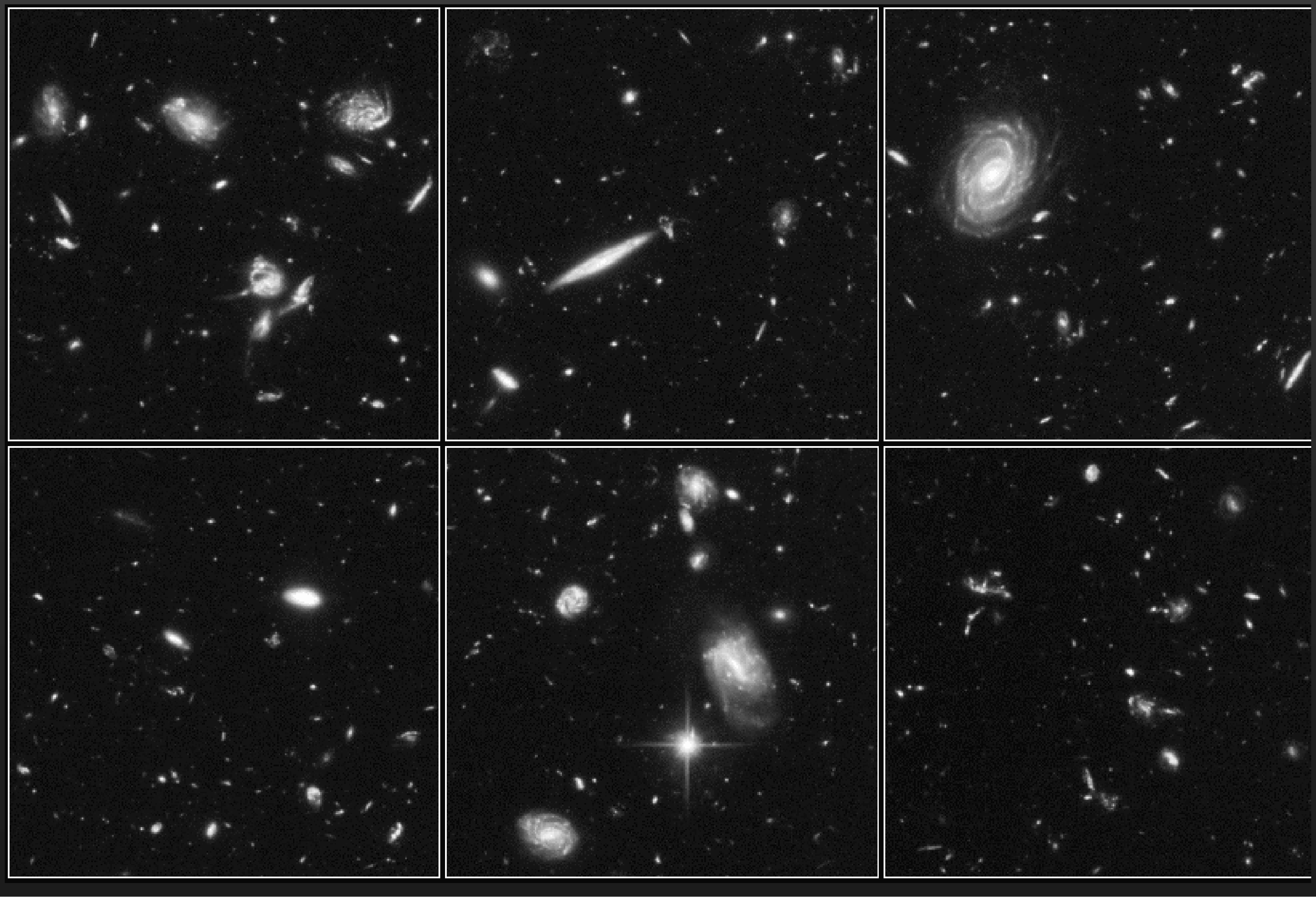
Science goals, technical calculations, planning strategy carried out by the HUDF Home Team.
http://www.stsci.edu/hst/udf/planning

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)

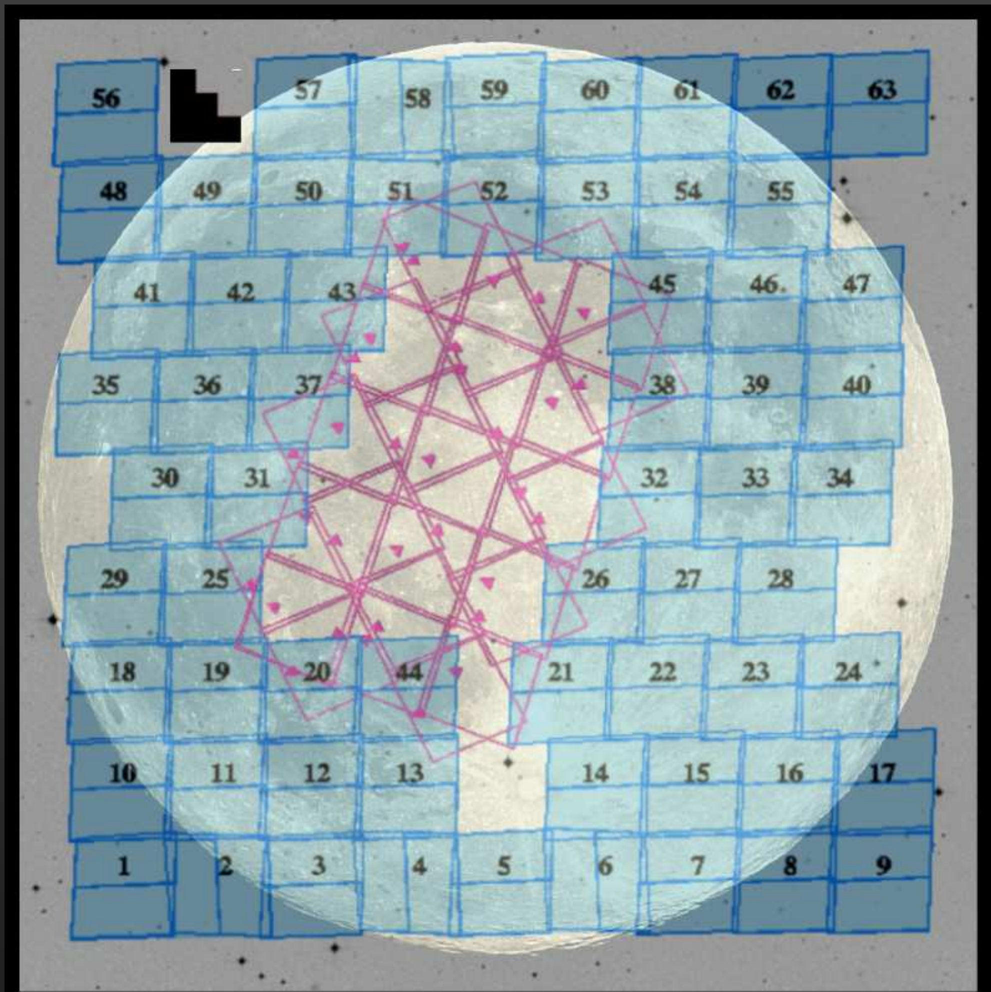
The GEMS Survey
(Galaxy Evolution from Morphology and SEDs)

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.



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

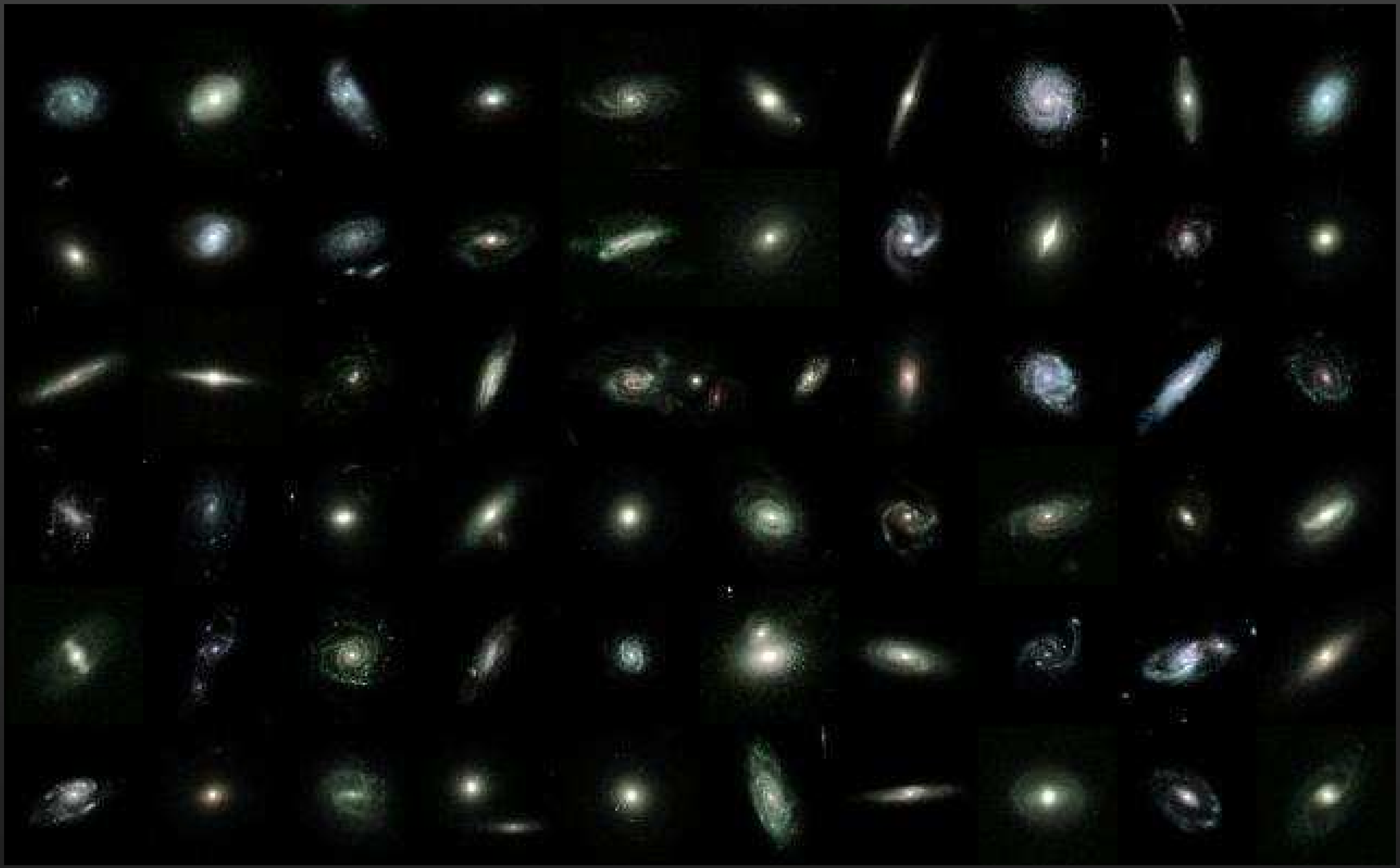
= 30’x30’= size of full moon on sky

= 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 data



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 ~40% of its present age!

Avoiding bandpass shifting

* GEMS galaxies have redshift z =0.2 to 1.2.

* If GEMS only used the F606W filter, then we would trace
  - à the rest frame optical (V or B) at z<0.5
  - à rest-frame ultraviolet within most of slice z =0.5 -1.2.

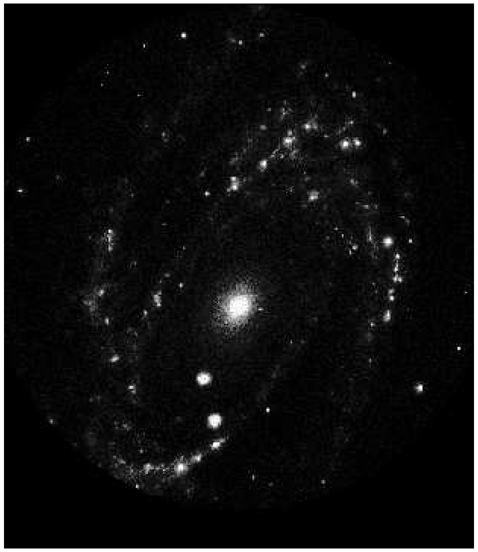
Redshift	Filter	Observed λ_{obs}	Rest-frame $\lambda_o = \lambda_{obs}/(1+z)$
0.25<z<=0.5	F606W	5900 A	4900 to 3930 A = V to B
0.5<z<1.2	F606W	5900 A	3930 to 2680 A = B to UV

* The change in the rest-frame bandpass traced is called "bandpass shifting", and should be avoided … why?

* The 2 filters in GEMS allow us to trace the rest-frame optical over the whole redshift interval z=0.2 to 1.2 by using the right filter in the right slice

Redshift	Filter	Observed λ_{obs}	Rest-frame $\lambda_o = \lambda_{obs}/(1+z)$
0.25<z<=0.5	F606W	5900 A	4900 to 3930 A = V to B
0.5<z<1.2	F850LP	9100 A	6000 to 4200 A = V to B

“Bandpass shifting” in M81



Rest-frameUltraviolet

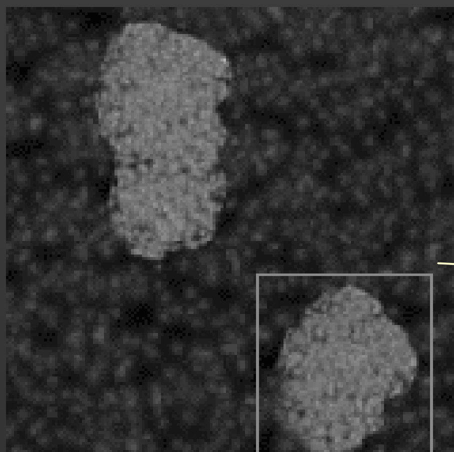
Rest-frame visible light (B, V)

A galaxy looks very different in rest-frame UV and rest-frame optical

From Wien’s law : the temperature and hence mass of stars dominating the light in each rest-frame band are very different

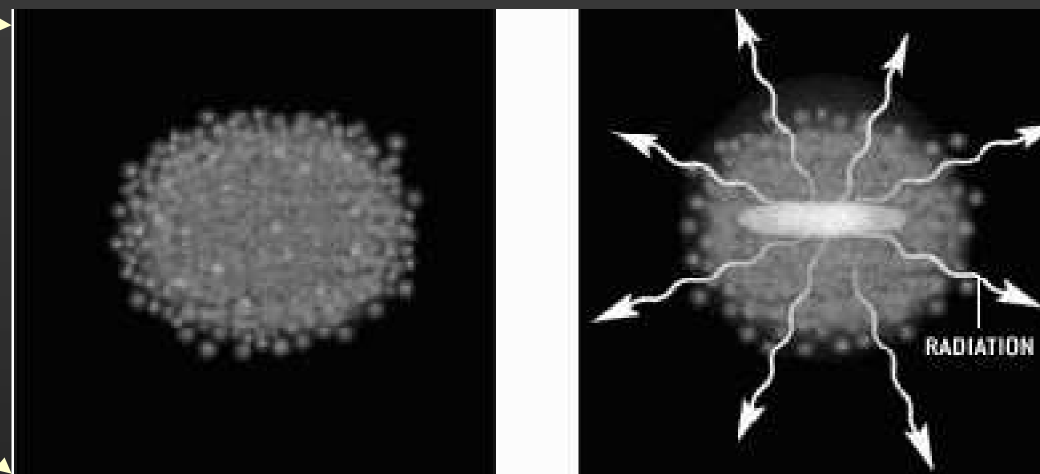
Hierarchical Λ CDM models of Galaxy Evolution

Formation of proto-galaxies in the early Universe



Dark matter (DM) = red; Baryons (gas or/and star) =blue.

- Initially (DM + gas) are coupled and form a fluid that is uniform except for some dense ‘clumps’ or protogalactic clouds.



Cosmic expansion thins out this fluid , but in the dense proto-galactic cloud gravity eventually wins over expansion

à DM is non-dissipative and stays in a 3-D halo

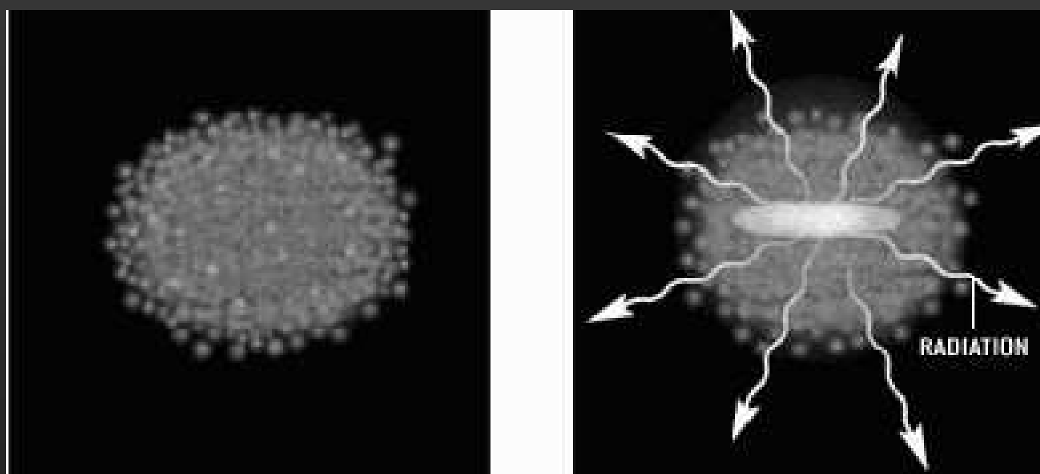
à Gas radiates and undergoes dissipative collapse to form a flat thin gas disk inside DM halo

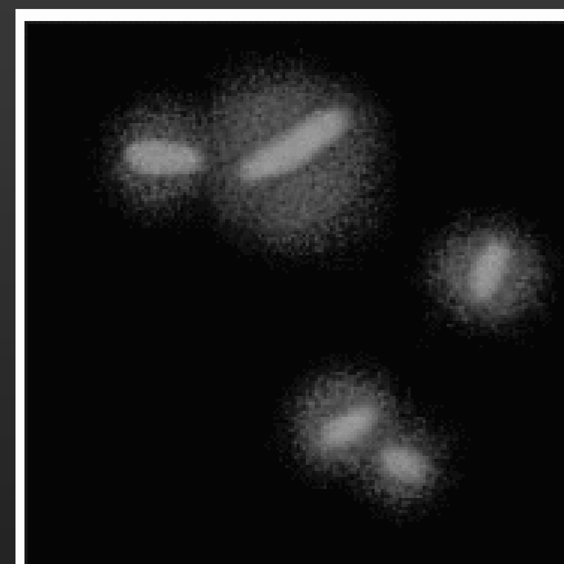
à This gas disk may form stars to produce a BULGELESS exponential stellar disk

Hierarchical Λ CDM models

* Hierarchical Λ CDM models refer to models where the dark matter is predominantly cold dark matter (CDM) and Ω_Λ i s significant e.g., 0.7.

* Hierarchical Λ CDM models predicts that DM halos (with the baryonic disk embedded inside) will undergo successive mergers to form larger DM halos.



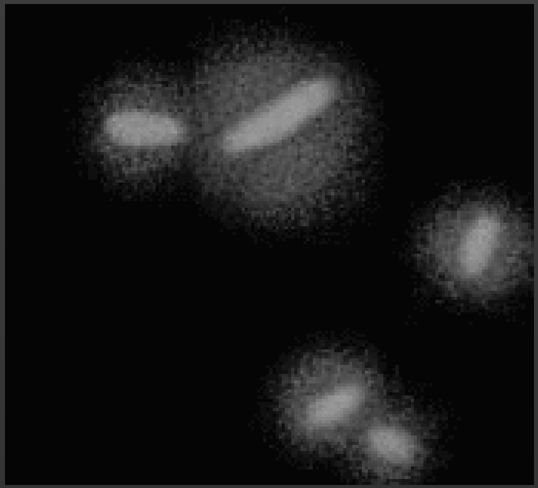


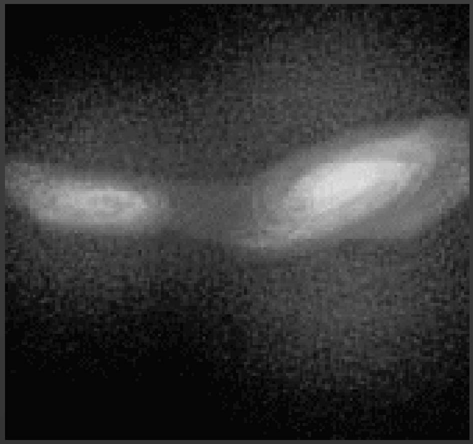
If baryons (mostly gas+some stars) follow the merger pattern of their parent DM halos, then in hierarchical Λ CDM models

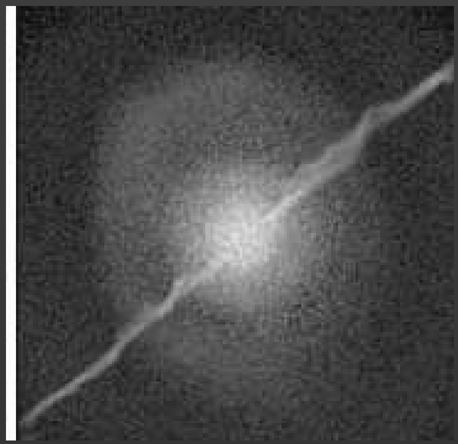
à galaxies grow from small-mass systems to larger-mass system (bottom up scenarios)

à massive galaxies form late in time, while low mass galaxies already exist at early times

From 2 low mass bulgeless disks à the bulge of a spiral







Each small DM halo has a baryonic disk embedded inside: the disk is made of gas and some stars, and is BULGELESS

Small DM halos undergo successive mergers to form larger DM halos.

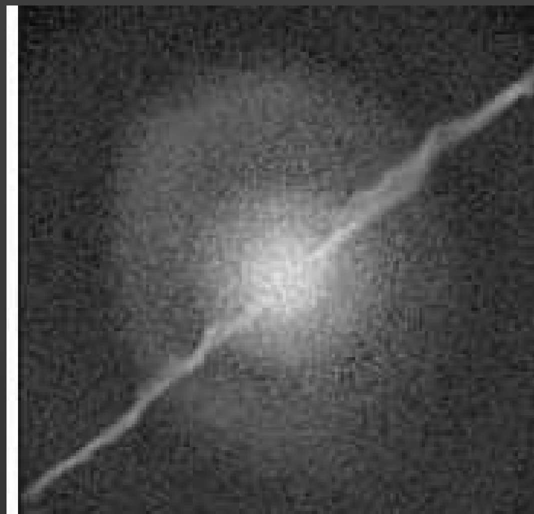
Major merger of 2 low mass (M~ few x 10^7 Mo) bulgeless stellar disks

à leads to violent relaxation in the stars

à produces a 3-D distribution of stars with a de Vaucouleurs $R^{1/4}$ surface brightness profile: this is the bulge of of a low mass spiral

NB: This process may perhaps fuel and grow a central black hole…so that bulges and black holes grow together to produce the BH-Bulge relation observed today

From a bulge à a spiral (B+D) galaxy à an elliptical galaxy



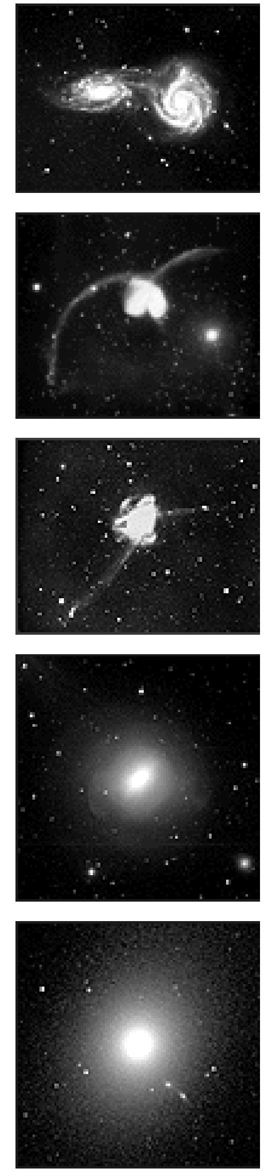
De Vaucouleurs $R^{1/4}$ bulge of a low mass spiral

Stellar bulge acquires low angular momentum gas, which forms a larger disk around the bulge. The resulting system is a spiral galaxy with a de Vaucouleurs bulge surrounded by an exponential disk

Spiral galaxy (B+D)

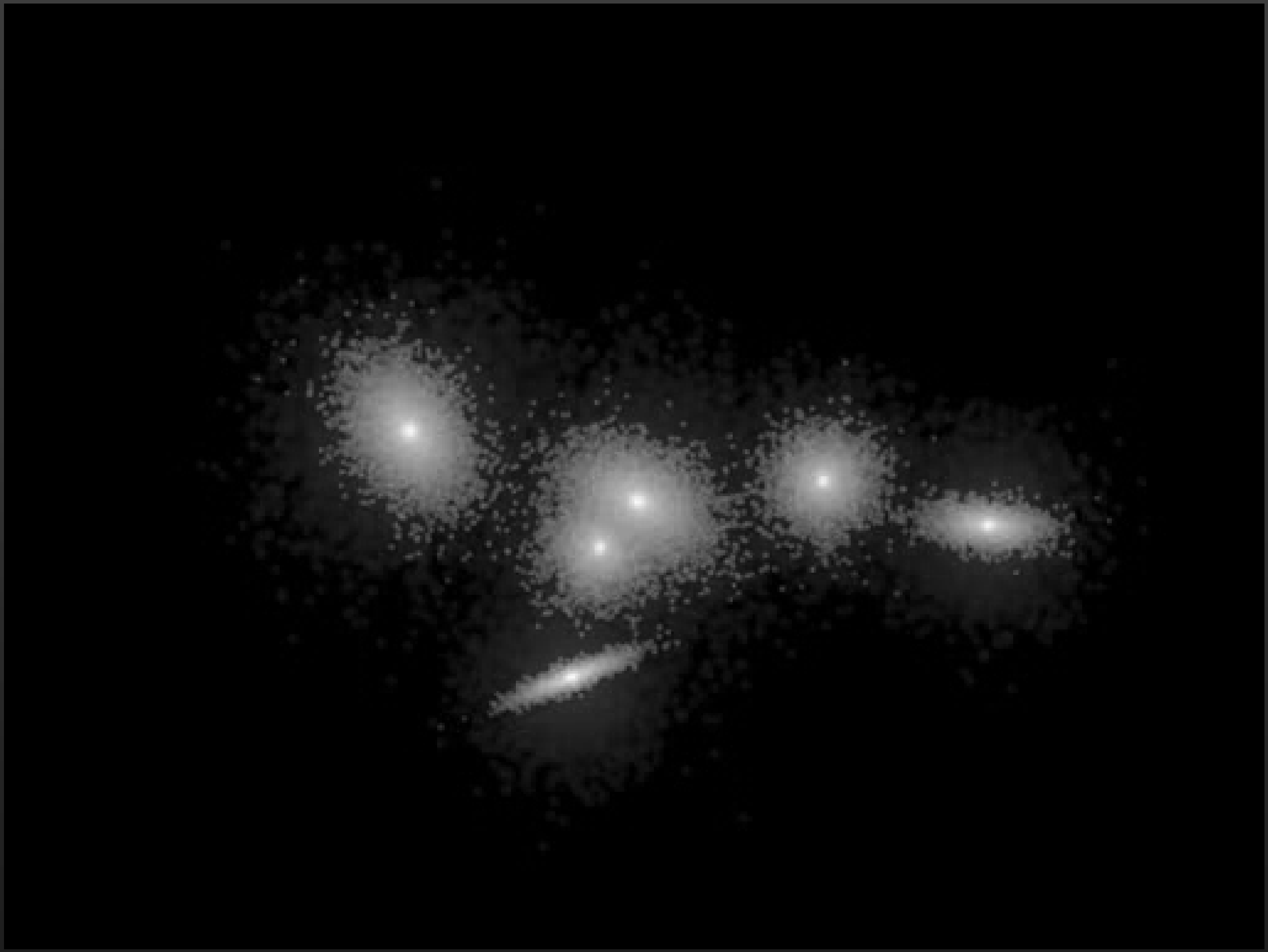
Major merger of 2 spirals of similar mass
à elliptical galaxy with a de Vaucouleurs $R^{1/4}$ surface brightness profile

Elliptical galaxy



Merger of 2 spirals (with or w/o bulge) of large & similar mass produces an elliptical galaxy!

Producing cD or giant E via mergers of multiple galaxies in dense environments



Credit : Joshua Barnes (University of Hawaii)

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Figures from Lecture 27: Th Apr 27

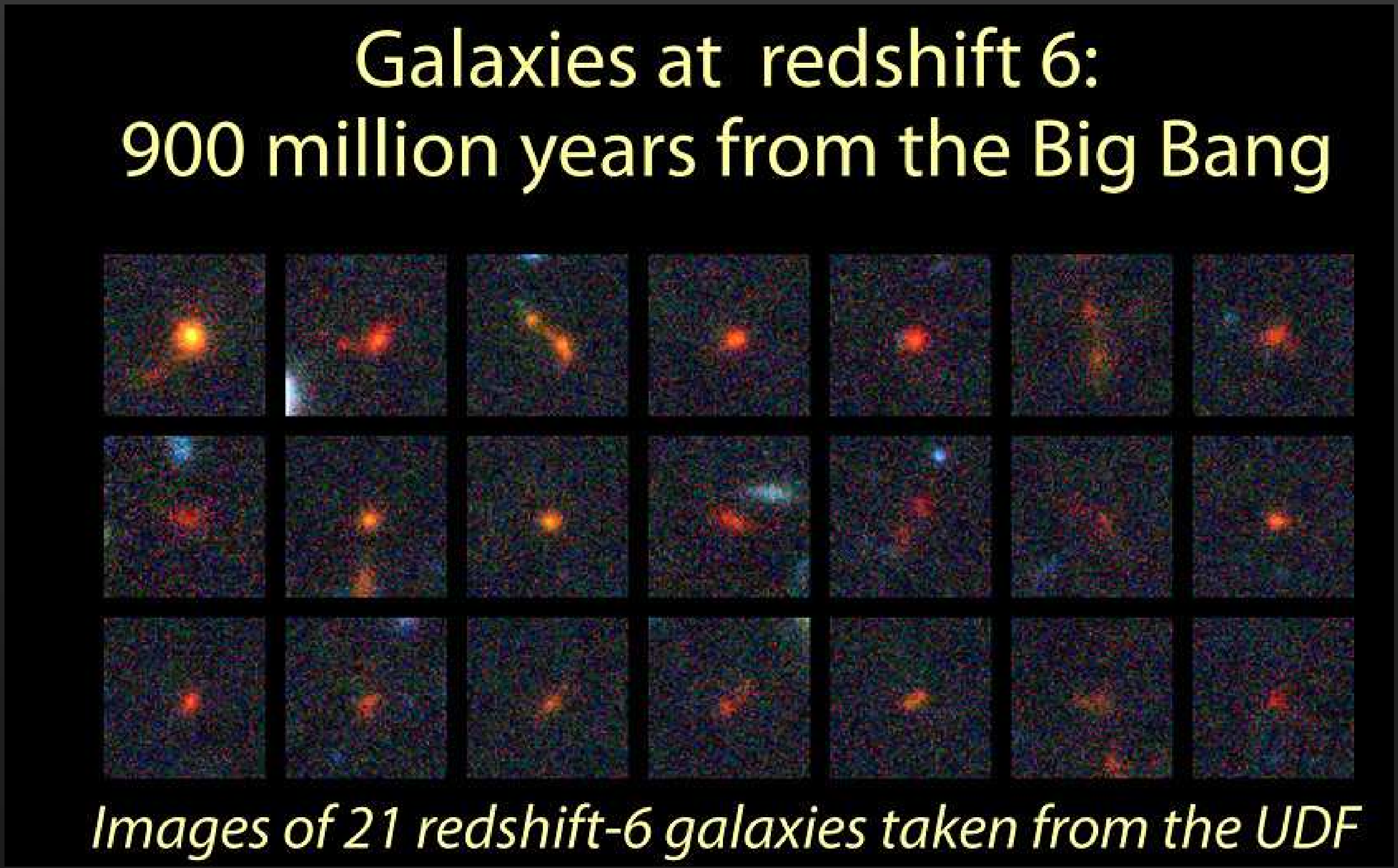
Observational Constraints on Galaxy Evolution from surveys (HUDF, GOODS, GEMS)

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)

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

à 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



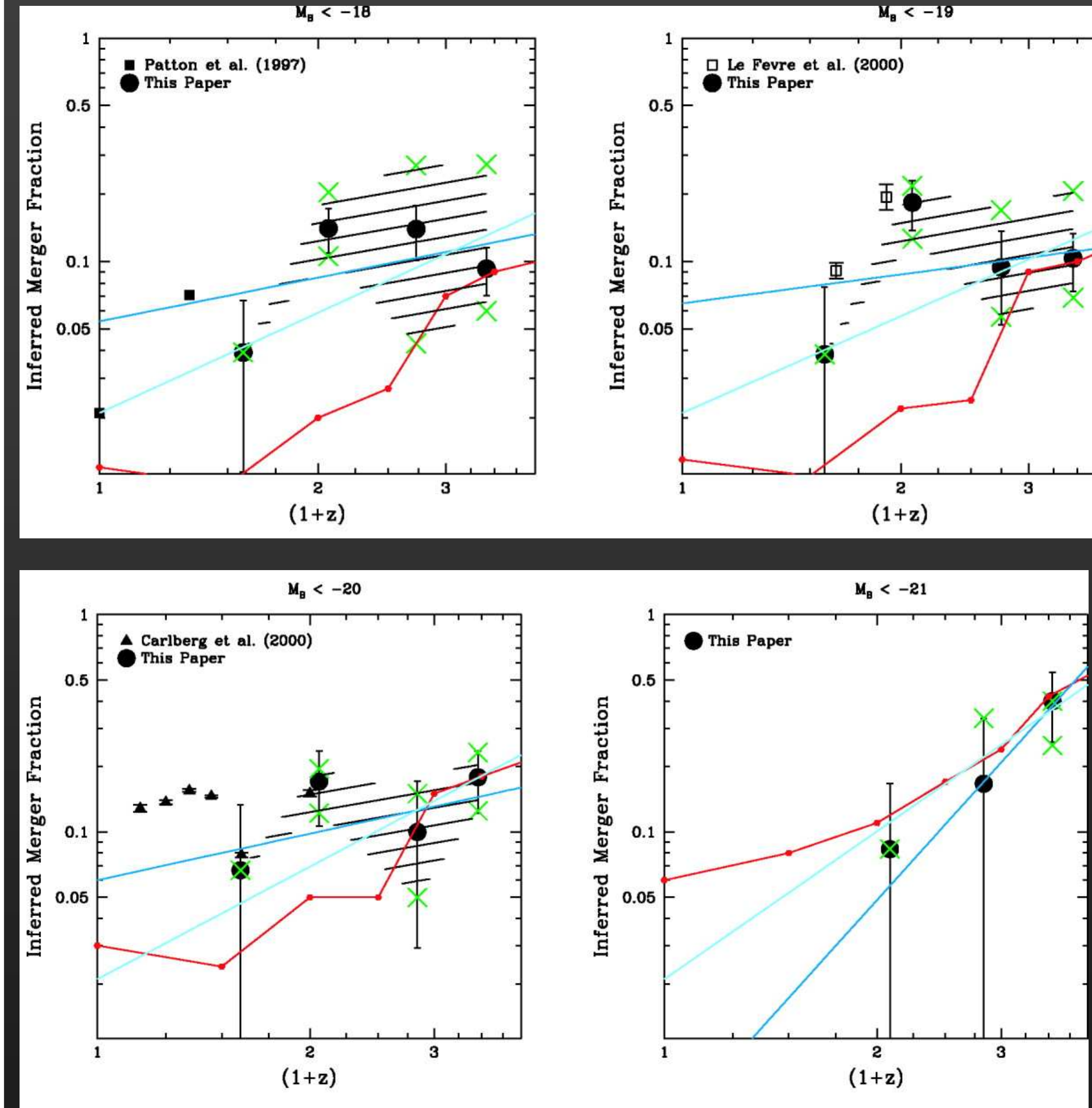
Illingworth et al 2006

2) Galaxy surveys constrain the merger history of galaxies from z=6 to 0

Merger history from z= 6 to 3 (age = 0.9 to 2.2 Gyr)

At z~6 to 5, Universe was a violent place with a high frequency of major and minor mergers

From z=5 to 2 (age =1.1 to 3.2 Gyr), the rare of mergers is still high, but starts to fall with time. By z~1, these mergers appear to have assembed systems that are similar in morphology, but less massive than present-day massive galaxies (E, Sa-Sd, S0)



(Conselice et al 2003)

Merger history from z= 2.5 to 1

(age = 2.6 to 5.8 Gyr)

This plot is based on GOODS data. It shows the fraction of galaxies undergoing mergers vs redshift, for four different luminosity (ie mass) range (from Conselice et al 2003).

* Dots and squares =data
* Blue lines = fits to data
* Red line = theoretical model.

From z=2.5 to 1, the merger fraction for faint and bright galaxies is constant or falls slightly

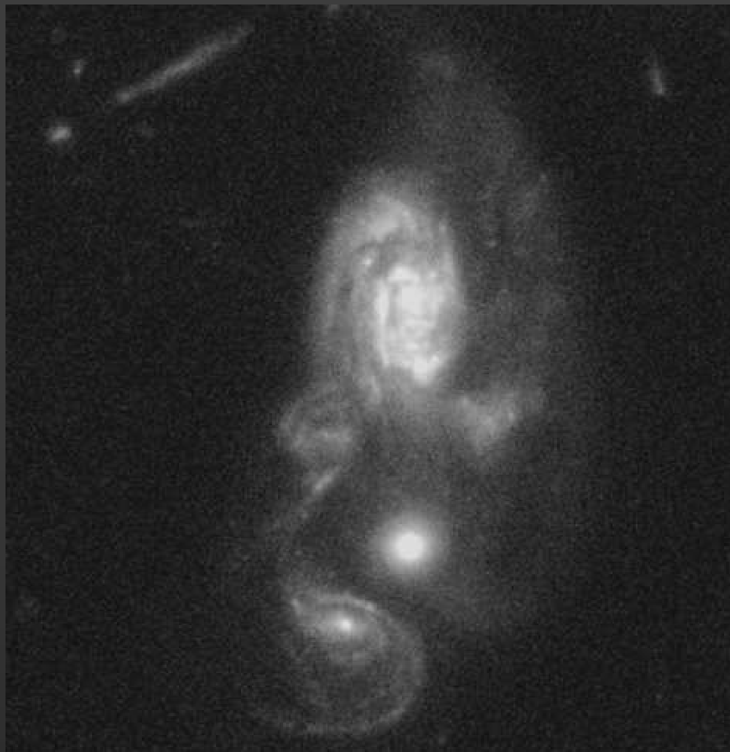
Merger history from z =1 to 0

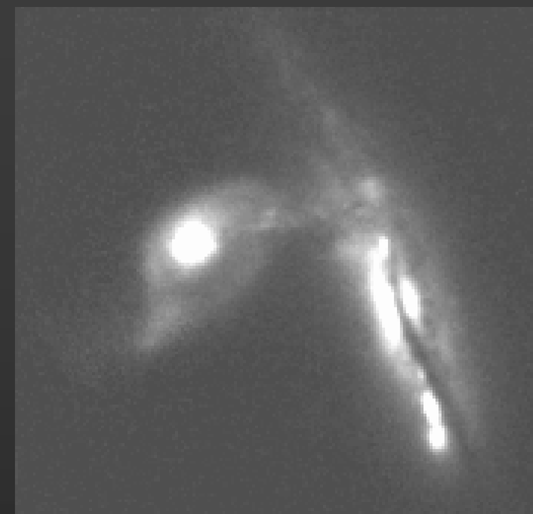
(age = 5.8 to13.7 Gyr)

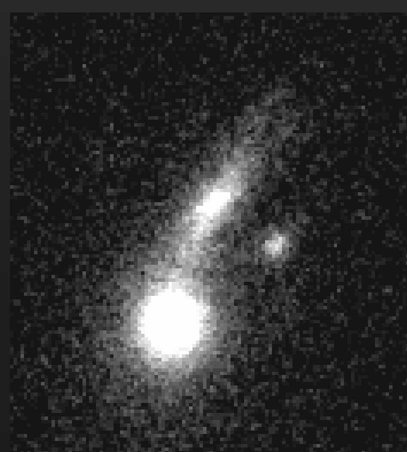
The errror bars on GOODS data points at z<1 are large b/c GOODS samples a small volume (ie few galaxies) at z<1 .

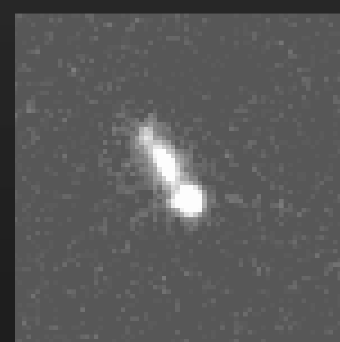
Can get better constraints on the merger history of galaxies from z=1 to 0, over last 9 Gyr using GEMS data (Summer project)

Example of Interacting galaxies at early epochs (lookback times of 2 to 9 Gyr) from GEMS and GOODS surveys

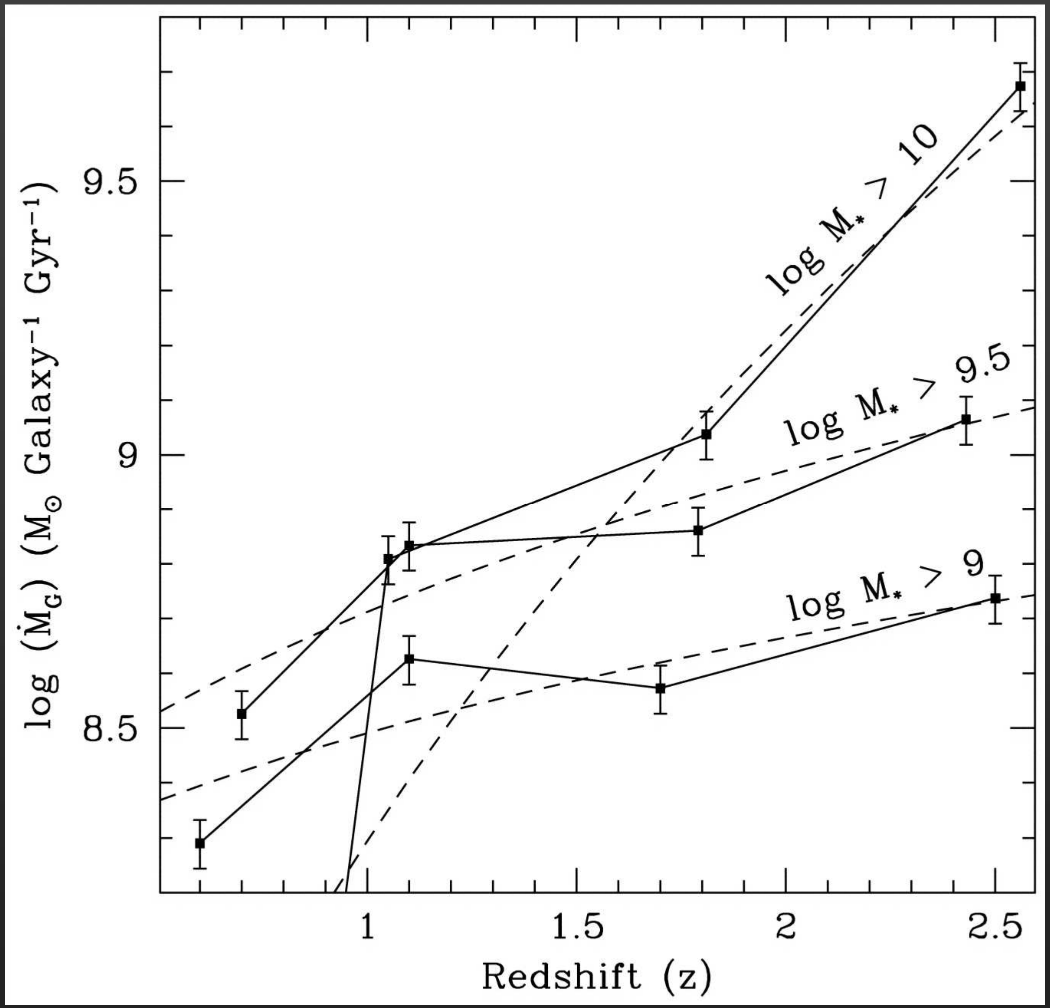








Merger history of galaxies is tied to their stellar mass assembly history



(Conselice et al 2003)

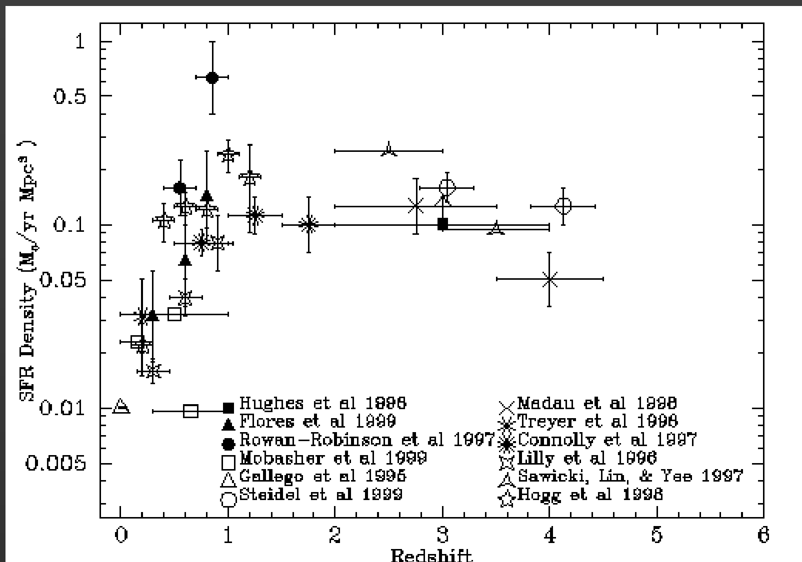
This plot is based on GOODS data. Data points (solid squares) show the stellar mass accretion rate per galaxy (in solar masses per galaxy per Gyr) vs redshift, for galaxies with stellar mass above 10^10, 10^9.5, 10^9 Msun

From z=2.5 to 1 (age= 2.6 to 5.8 Gyr)

à the stellar mass accretion rate falls with time for high   mass and low mass galaxies

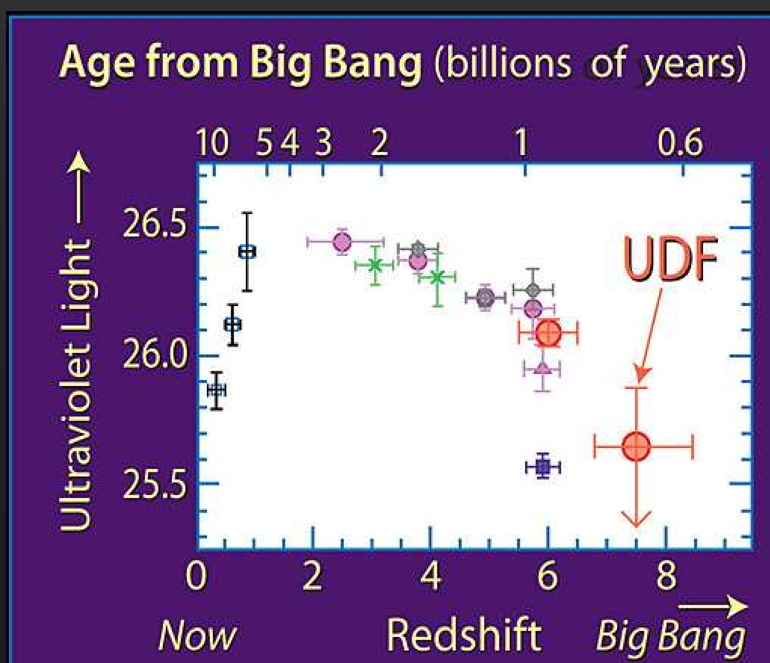
à Galaxies grew their mass most rapidly at earlier times and the absolute growth rate falls off at later times

3) Galaxy surveys trace the star formation history of the Universe

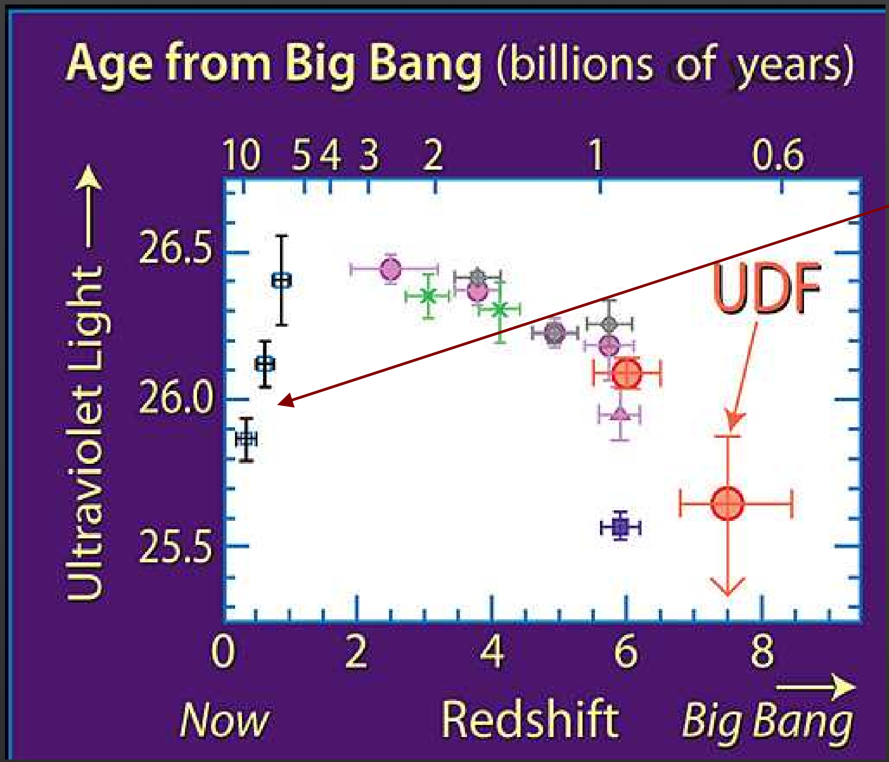


The plot shows the cosmic star formation rate density, namely the rate at which new stars are forming in the Universe (in units of solar masses per year per Mpc^3) versus redshift for z=4.5 to 0 (age= 1.3 to 13.7 Gyr)

The first version of this plot in 1998, where SFR is traced via UV light is the "famous Madau plot"



The HUDF data added the z=5 and z=6 (age = 0.9 to 1.1 Gyr) points in 2006



Notice that from z=1 to 0 (age of the Universe = 5.7 to 13.7 Gyr), there is a dramatic fall in cosmic SFR density, by more than a factor of 10…! Why is this?

à galaxies run out of gas (fuel) as they have converted all their gas supply into stars

à the rate at which galaxies experience m<u>ajor or minor mergers</u> (which compress existing gas into stars) falls from z=1 to 0? **(Summer Research Project using GEMS)**

à the rate at which galaxies accrete gas from <u>cosmological filaments falls</u>

à the internal structures of galaxies (e,g presence of bars) changes from z=1 to 0

4) How long have barred galaxies like the Milky Way been around?

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

GEMS result

à Barred spirals, similar to our Milky Way, were already abundant 9 Gyr ago, when the Universe was only 40% of its present age (Jogee and GEMS team, 2004, ApJ)

à Simluations show bars get rapidly destroyed in triaxial DM halos :hence, the abundance of bars implies that disk galaxies at z=1 have a DM halo that has very low triaxiality (Berentzen Shlosman & Jogee 2p006)