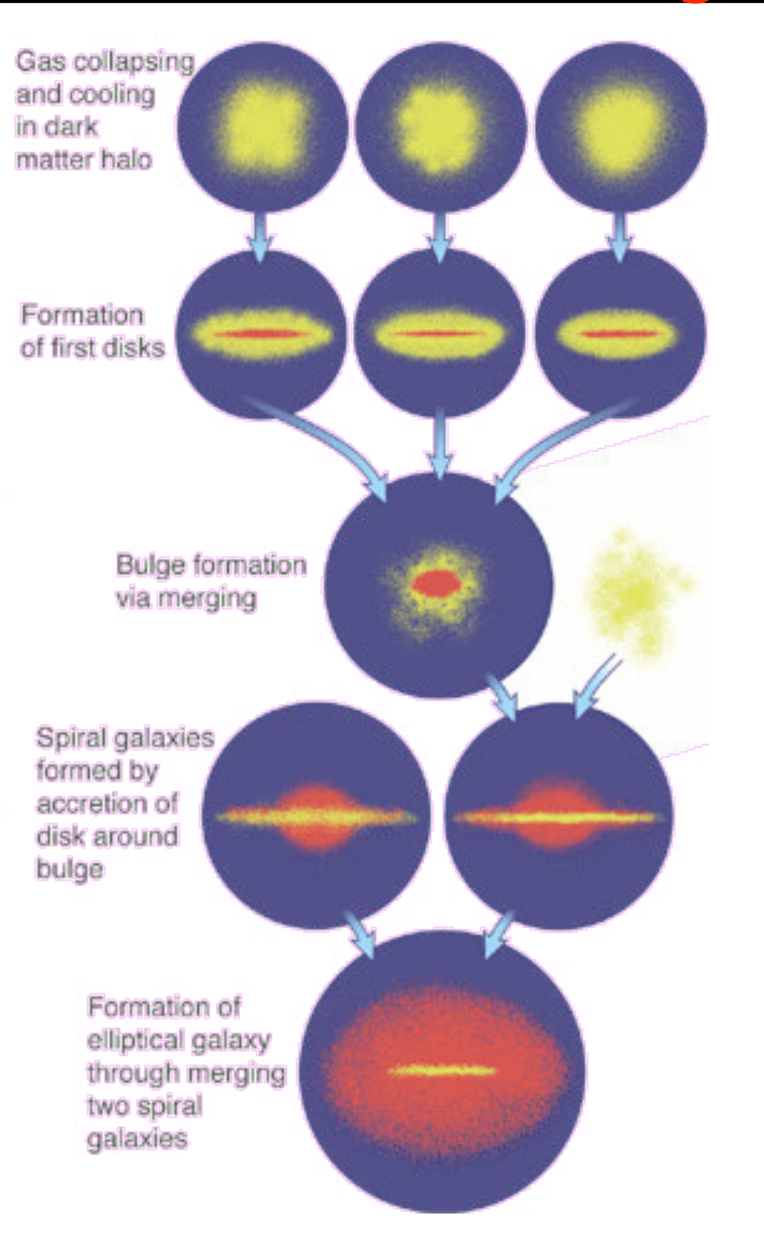
Hierarchical galaxy formation; disks merge to disk bulges and Ellipticals

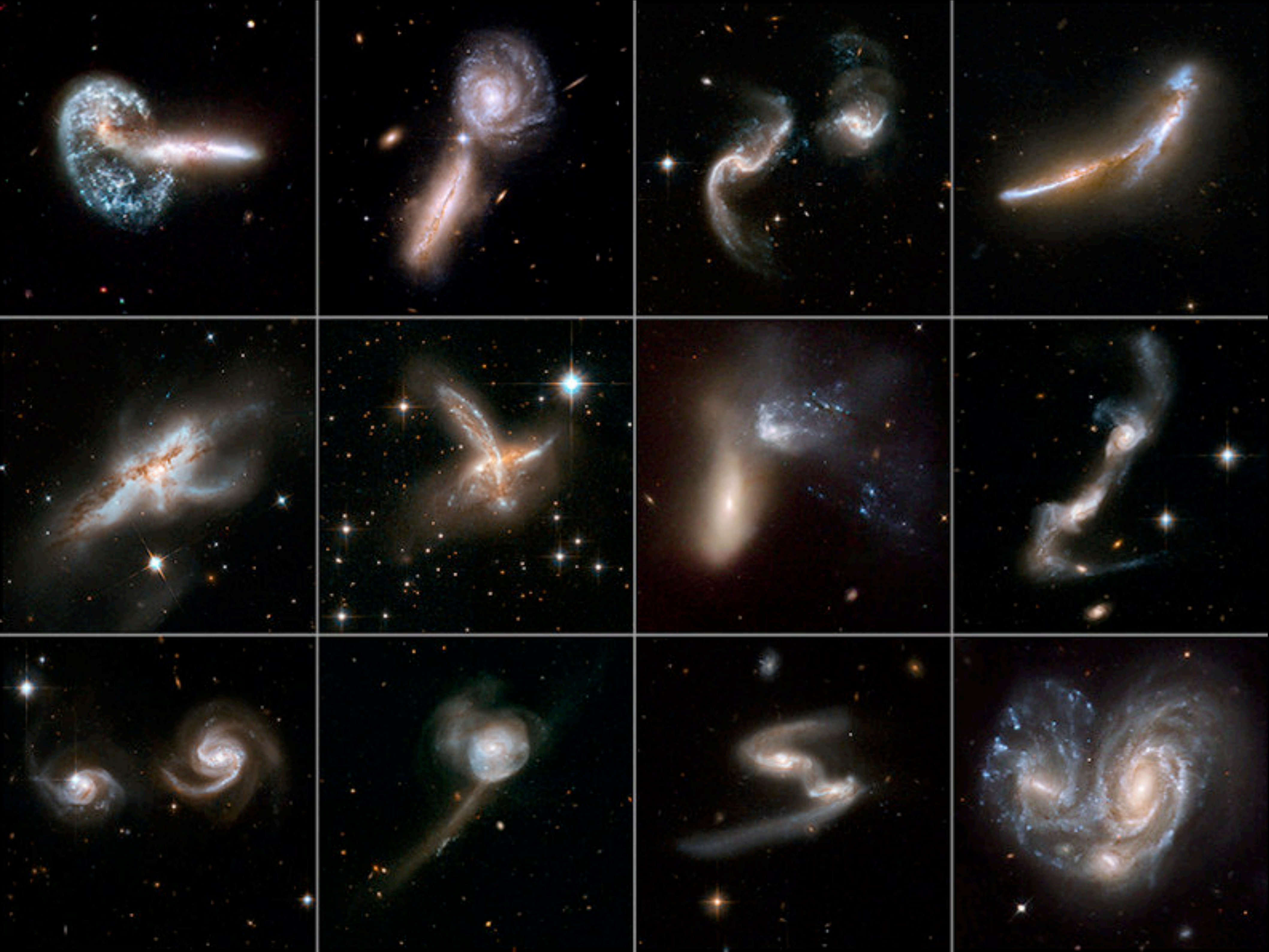


Blue: Dark matter Halo;
yellow: gas; red: stars

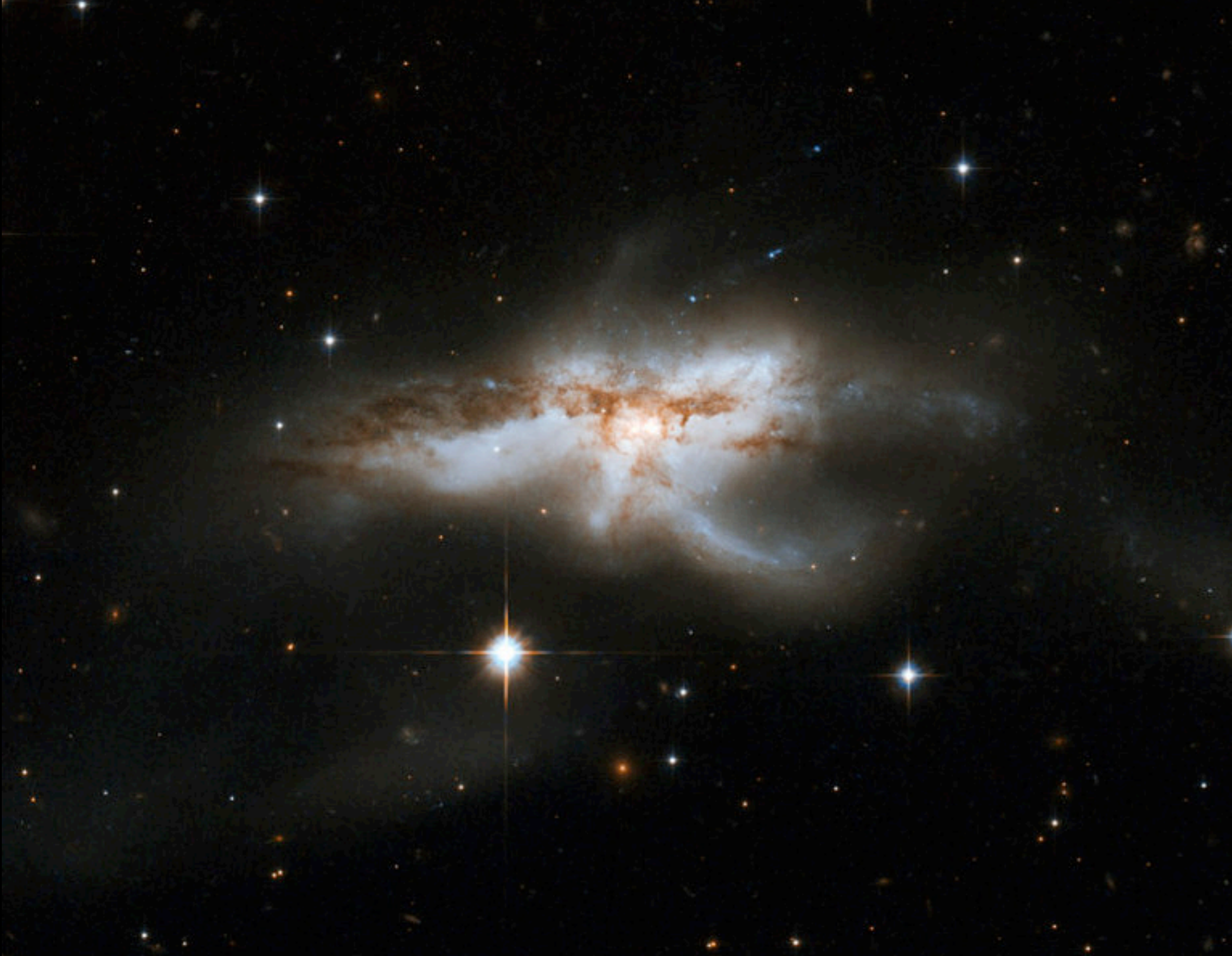
In a "hierarchical" scenario, smaller structures form first, and later merge into bigger ones:

Galaxies merge to form larger ones

Mergers of roughly equal-sized galaxies often (not always) turn Spirals into Ellipticals

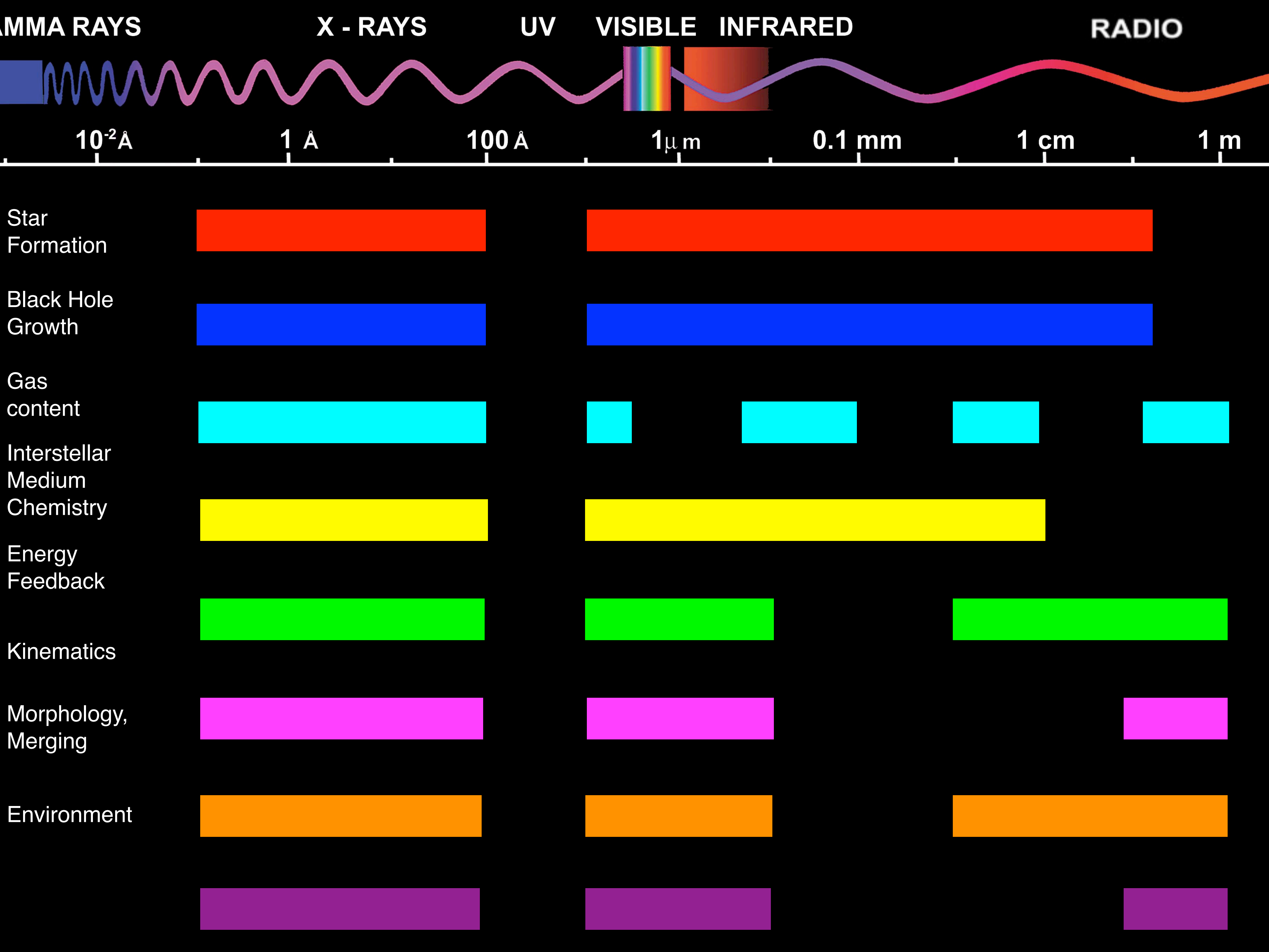



The Mice: Colliding Galaxies with Tails of Stars and Gas — NGC 4676
HUBBLESITE.org



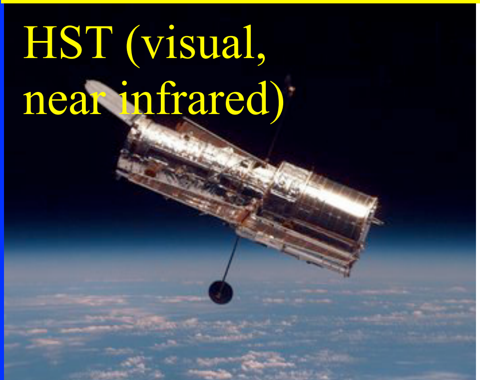
II. How did we learn about galaxy formation?

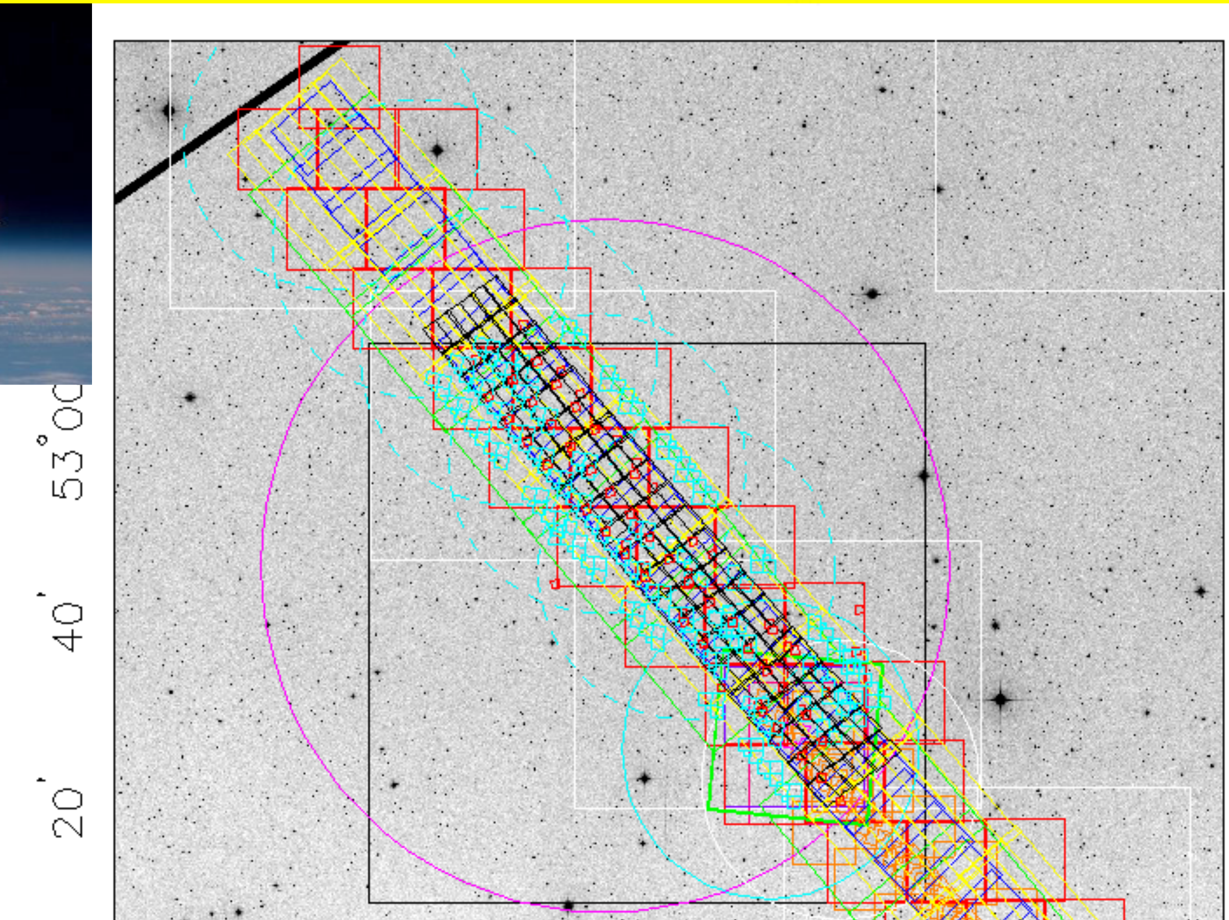
Deep Sky Surveys at many Wavelengths

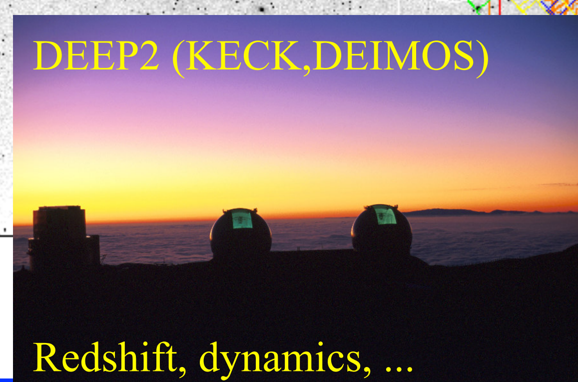


MMA RAYS
X - RAYS
UV
VISIBLE
INFRARED
RADIO
10^{-2} Å
1 Å
100 Å
1 μm
0.1 mm
1 cm
1 m
Star Formation
Black Hole Growth
Gas content
Interstellar Medium Chemistry
Energy Feedback
Kinematics
Morphology, Merging
Environment

Multiwavelength surveys: combined efforts to get the whole picture. A new era of astronomy: big collaborations, huge databases







Astronomers can look back in time:

light from very distant galaxies took billions of years to reach us

looking far is looking back

even more
distant galaxy

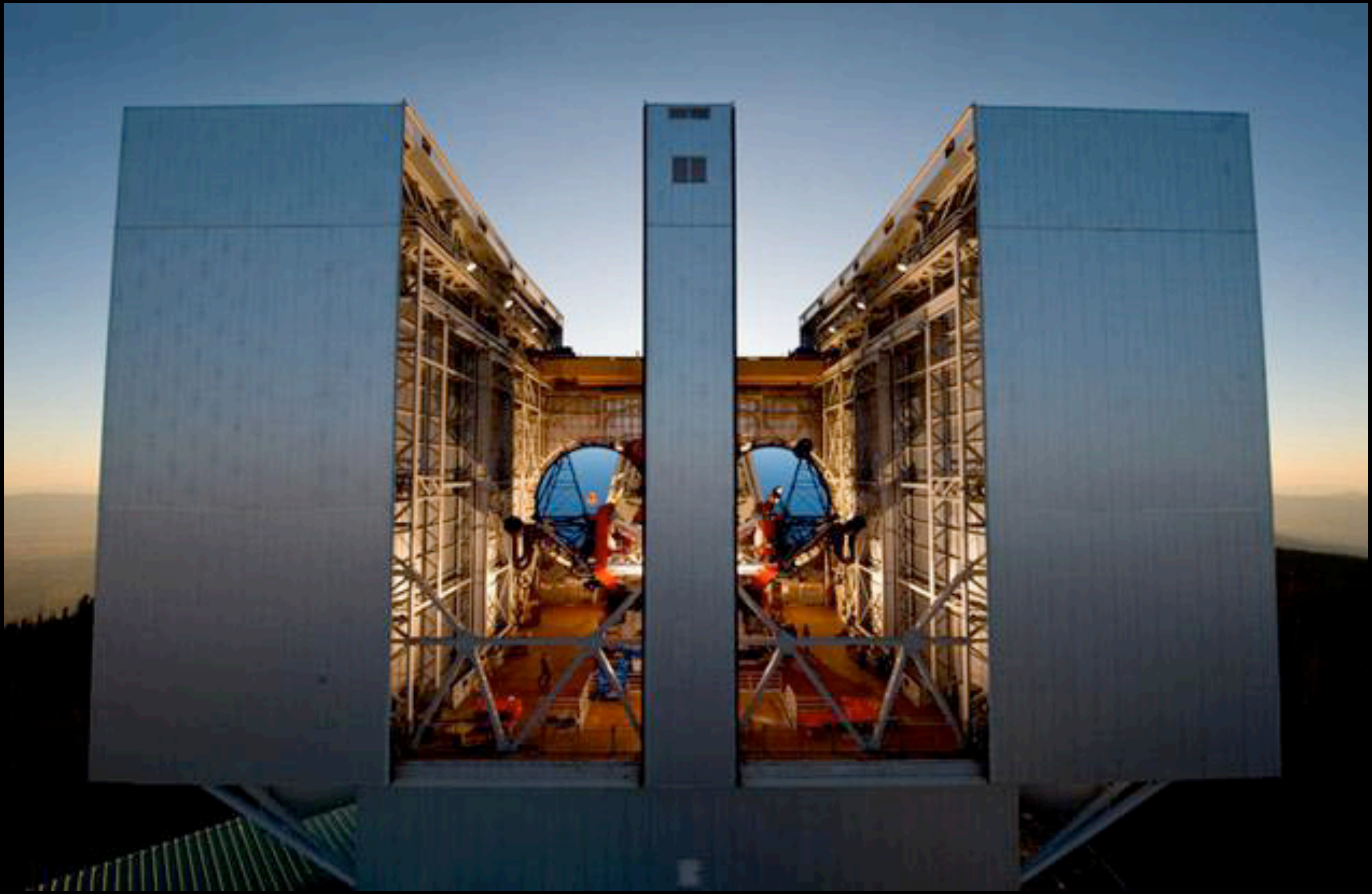
distant galaxy

nearby galaxy

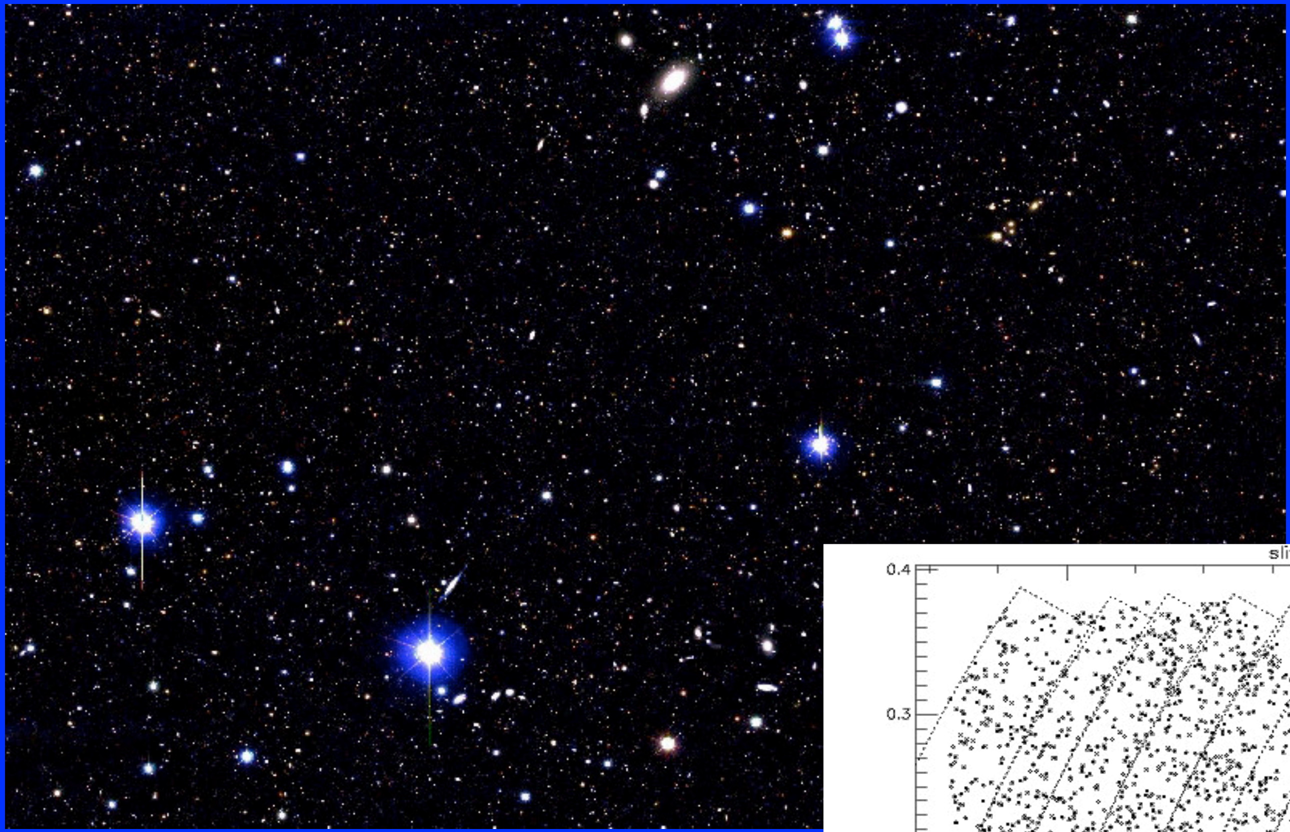
time light travels
to reach us

Long (billions
of years)

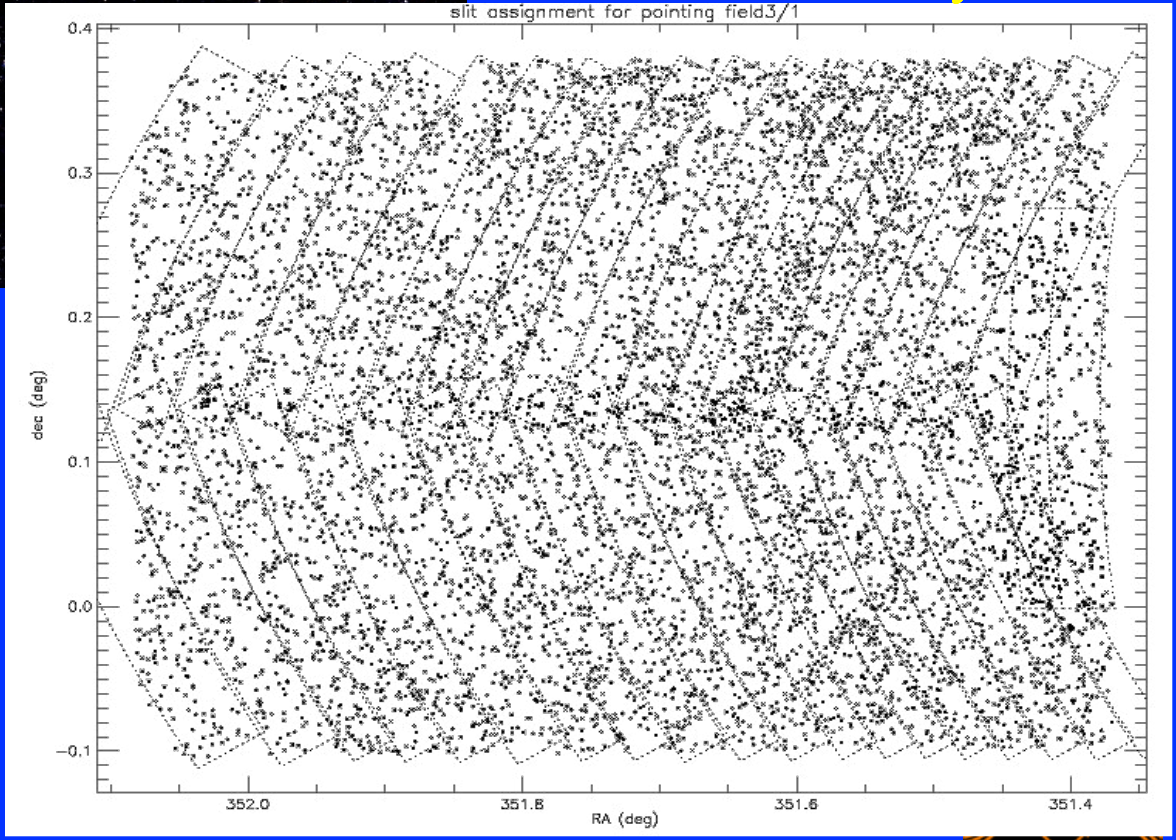
Short (millions
of years)



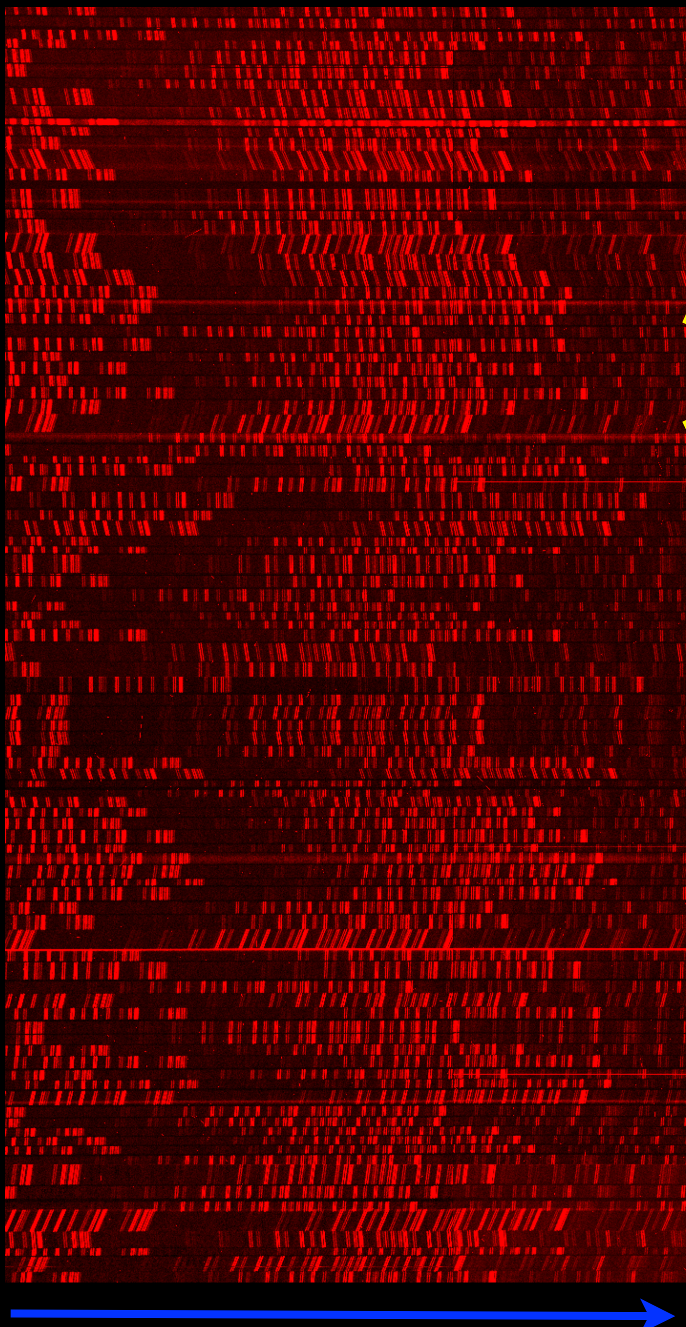
Large telescopes on the ground:
Spectroscopy gives each galaxy a "time stamp"



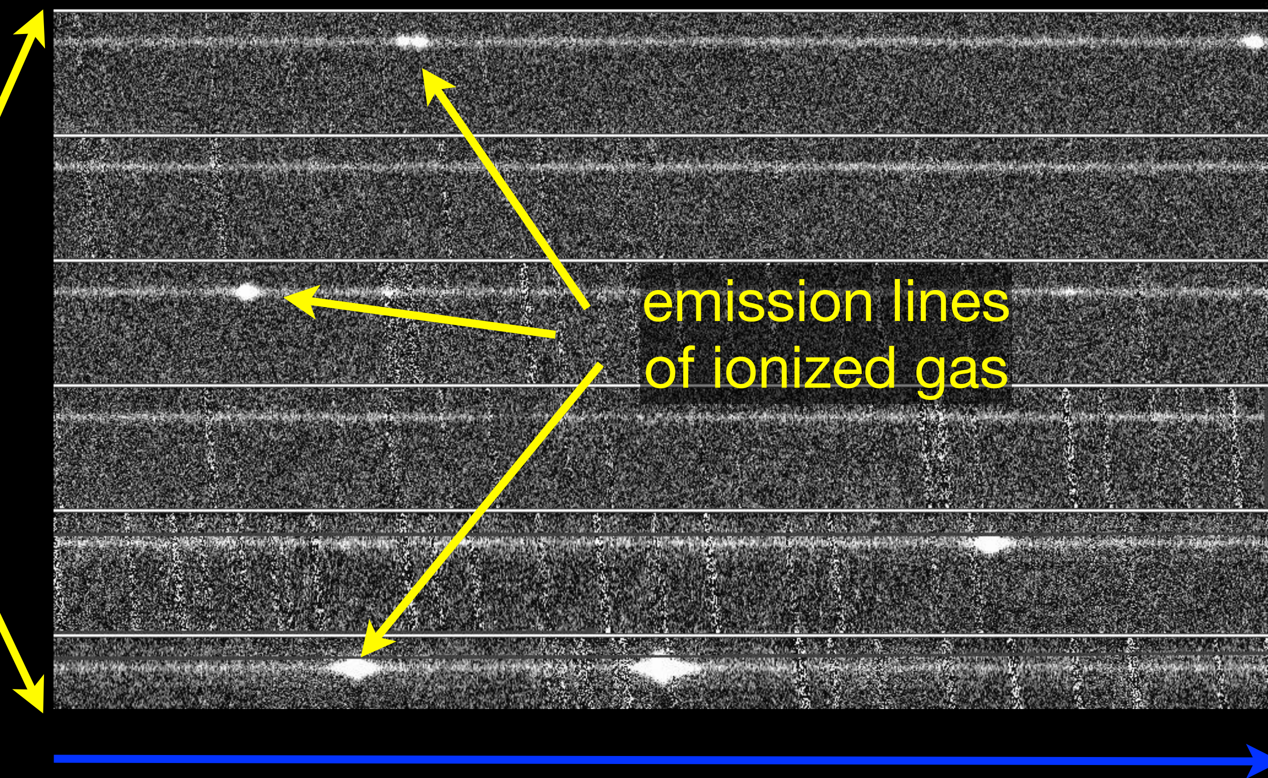
Overlapping slitmask layout



120 spectra of distant galaxies



wavelength



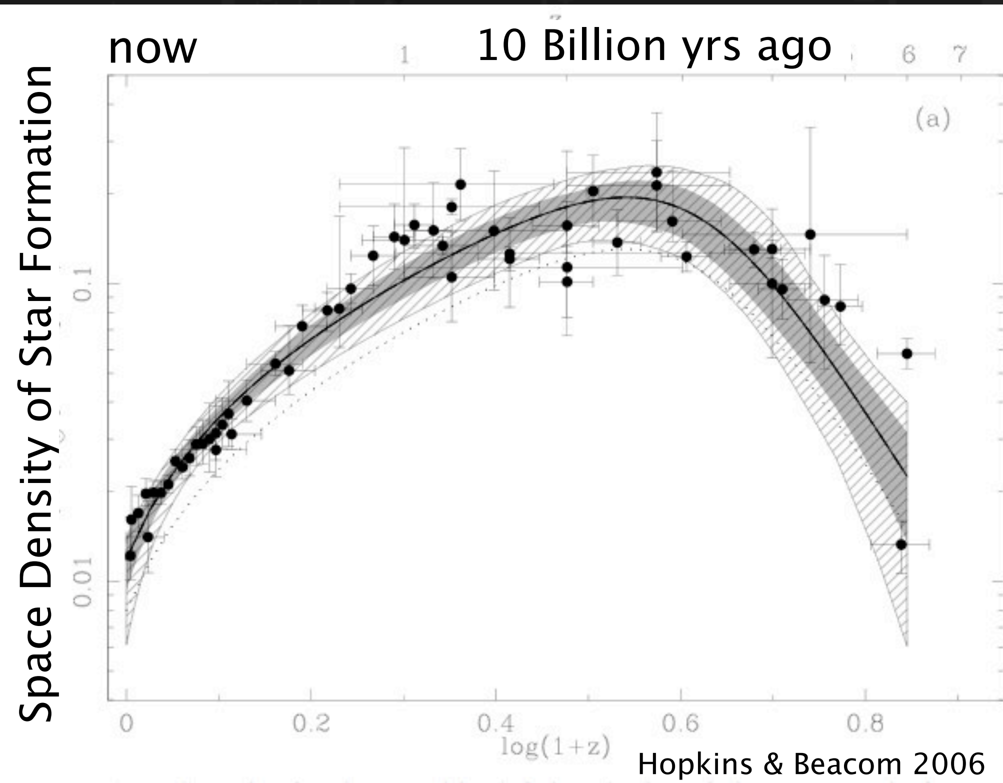
wavelength

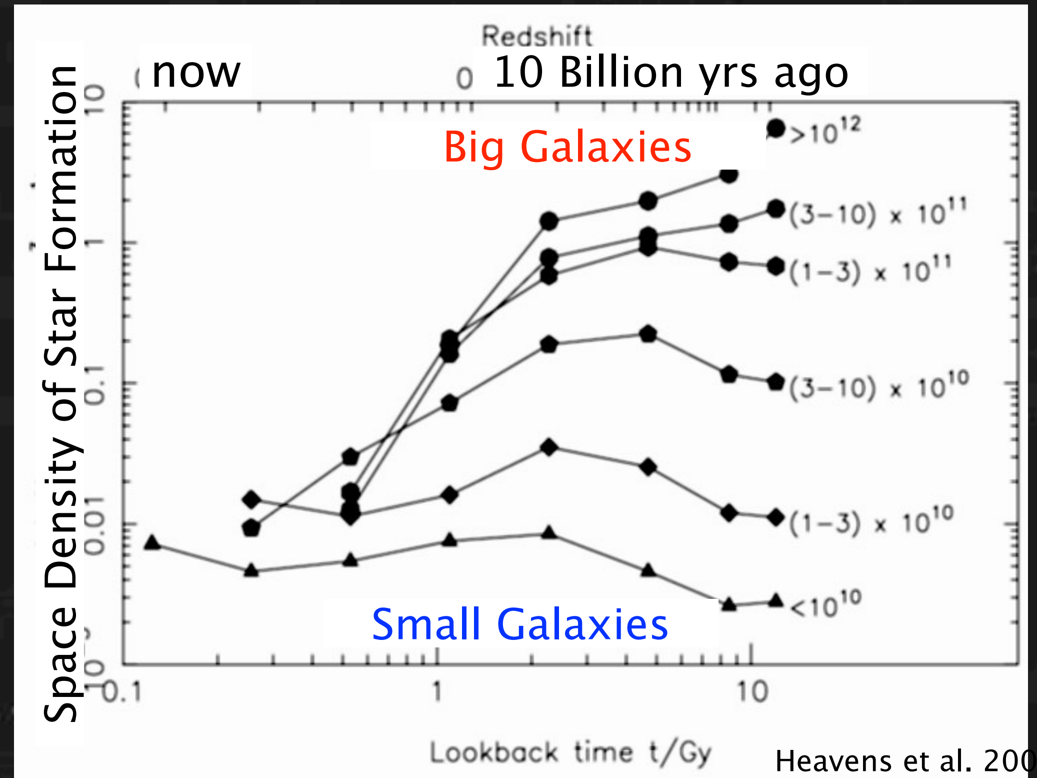
The emission lines are at longer wavelengths than measured in the lab: They are "redshifted".

This is because distant galaxies move away from us ("Doppler effect", expansion of the Universe).

The redshift (=velocity) measures the distance and how far we look back in time

Star formation in galaxies over the last 10 billion years





Co-moving star formation rate (SFR) density declined by ~x10

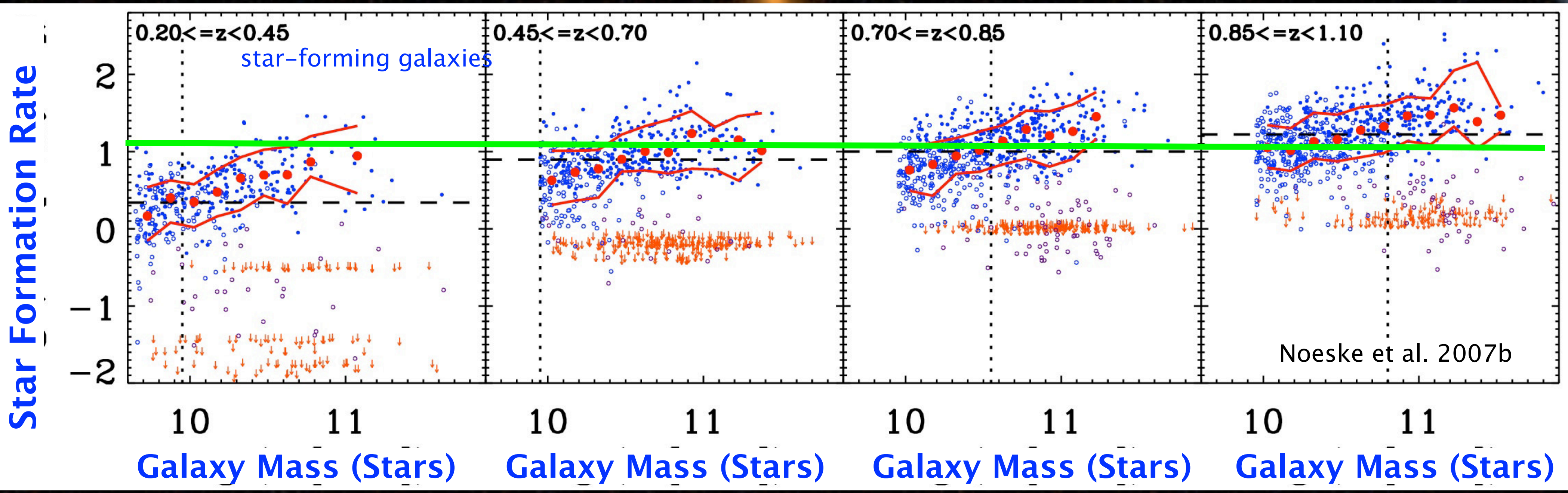
Galaxy star formation histories are mass-dependent:

massive galaxies formed bulk of stars quickly and early, less massive galaxies formed on longer timescales ("Downsizing")

Reason for declining star formation:

Galaxies run out of gas!

The Star Formation Rate-Stellar Mass Relation("Main Sequence")

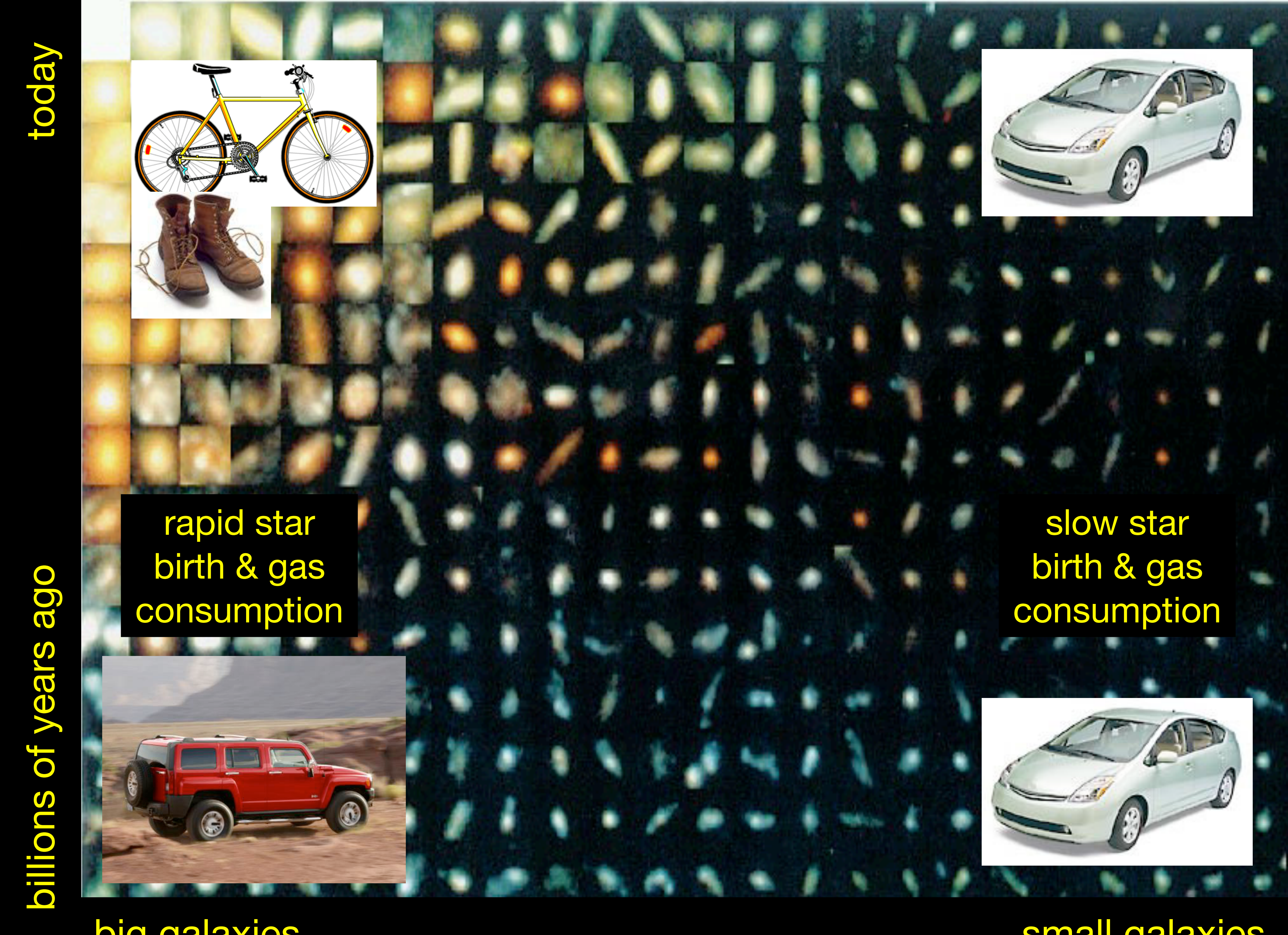


1) Star-forming galaxies form a defined relation:
SFR – stellar mass out to z>2.
Galaxies of similar mass had similar SF histories.

2) Range of log(SFR) ~±0.3 dex (1σ) at all z:

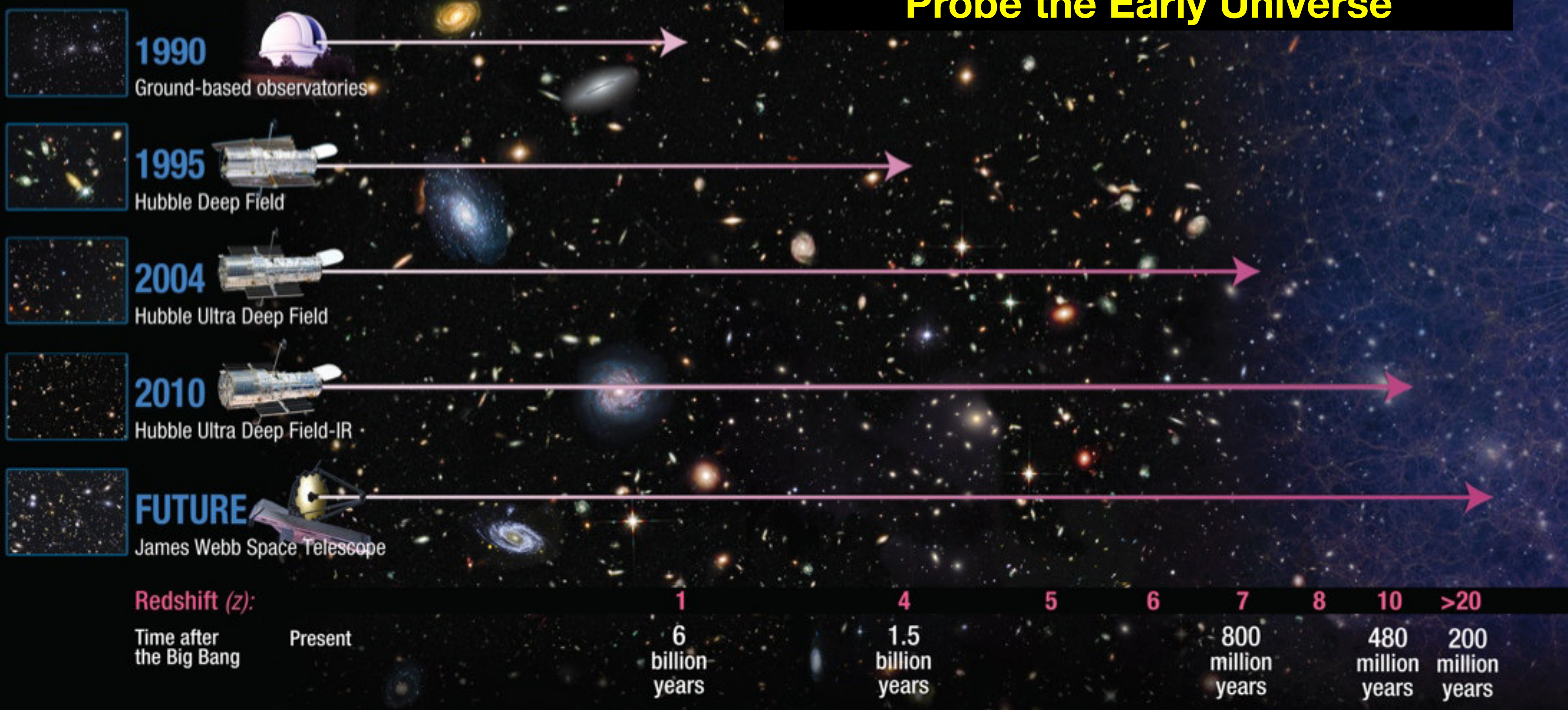
starbursts had only a modest, barely evolving role out to z~2
- New paradigm, rejects most popular earlier hypothesis.
- Constraint to effect of galaxy mergers on starbursts.

3) Normalization evolves strongly: SFR x1/6 from z=1 ... 0 (8 Gyr)
Evolution of SF since z~2 dominated by a gradual decrease of SFR.



(image: Driver 1998)

Hubble & JWST Probe the Early Universe



HST: currently the most sensitive telescope in the short-wavelength infrared (near-infrared): Can observe redshifted UV (star formation) from the most distant galaxies

JWST (launch: 2018) will be more sensitive, and reach longer infrared wavelengths: will reach even further back in time, and observe redshifted visible & infrared light in earliest galaxies

JWST will have much improved sensitivity to faint distant galaxies:

First Stars & Galaxies

Small galaxies across cosmic time

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