Gas and star-formation in galaxies over cosmic history

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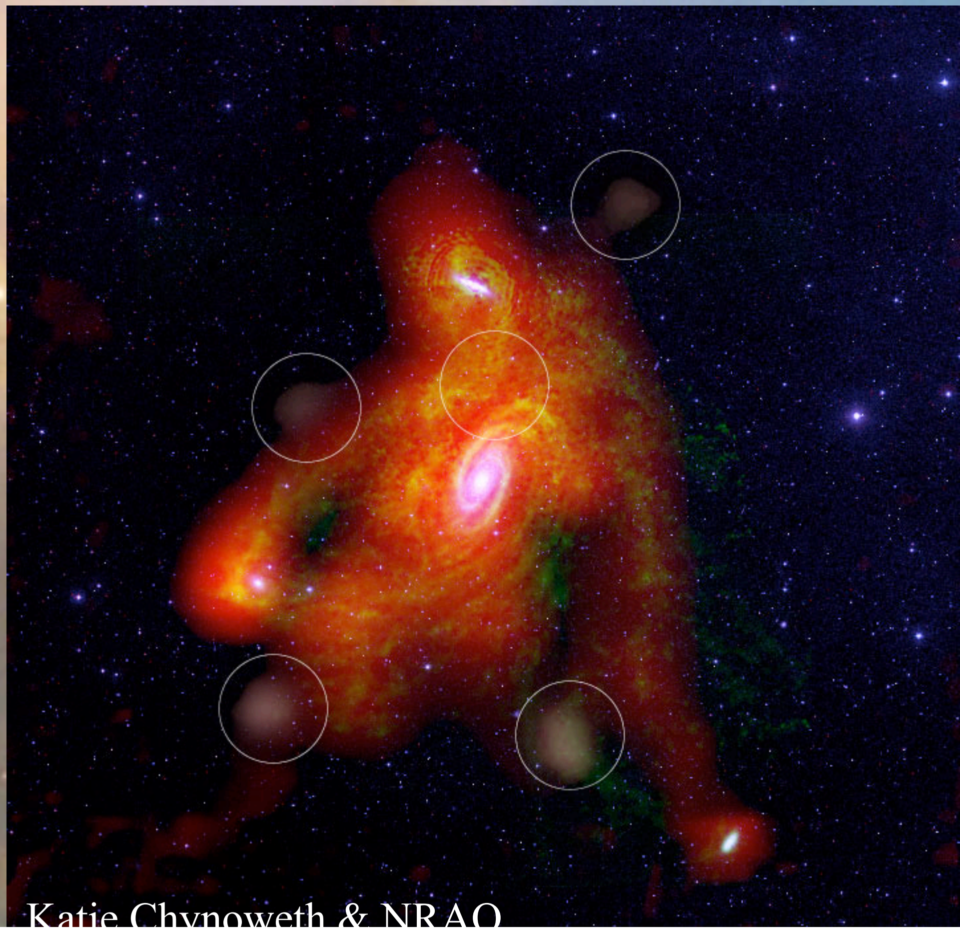
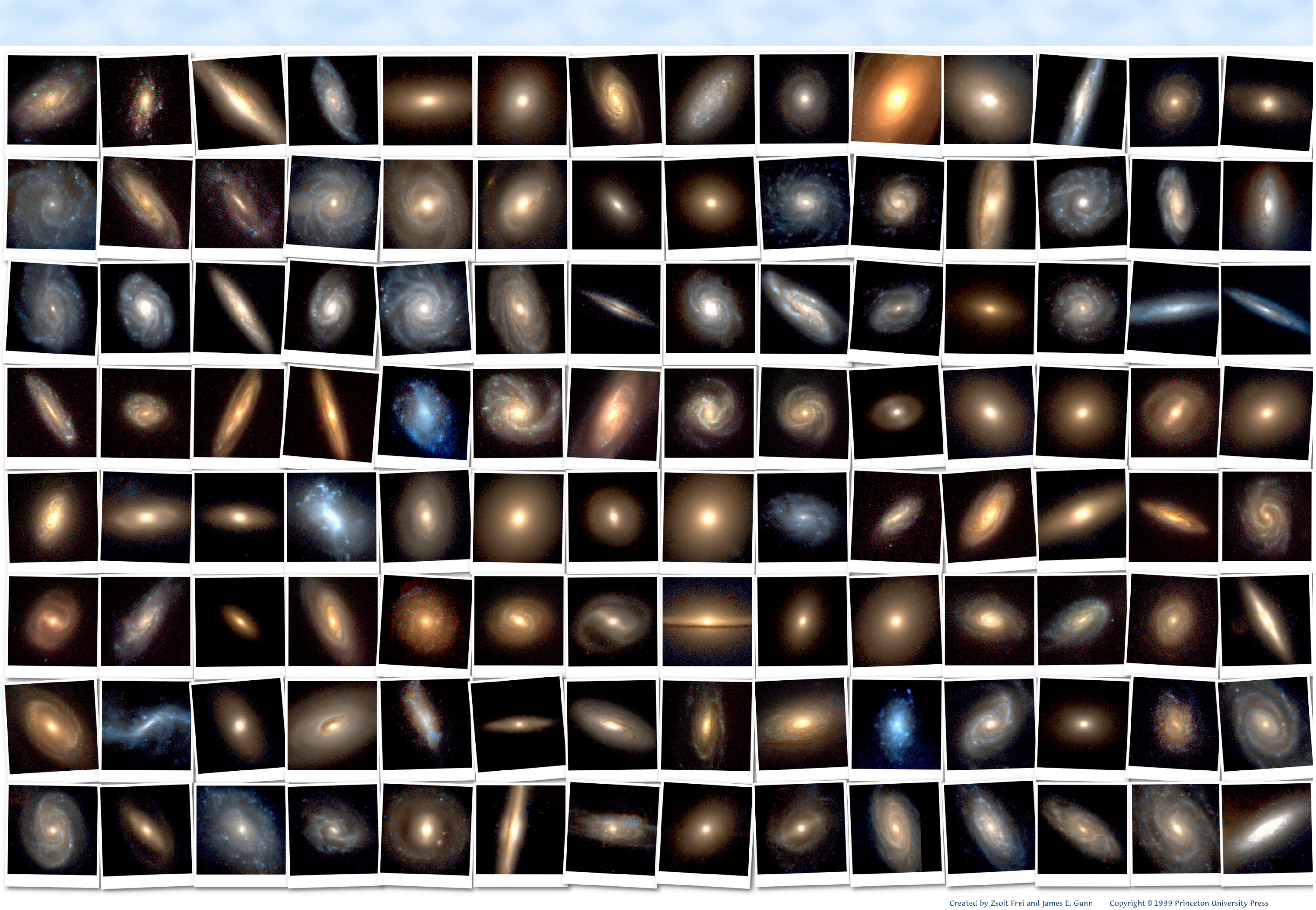
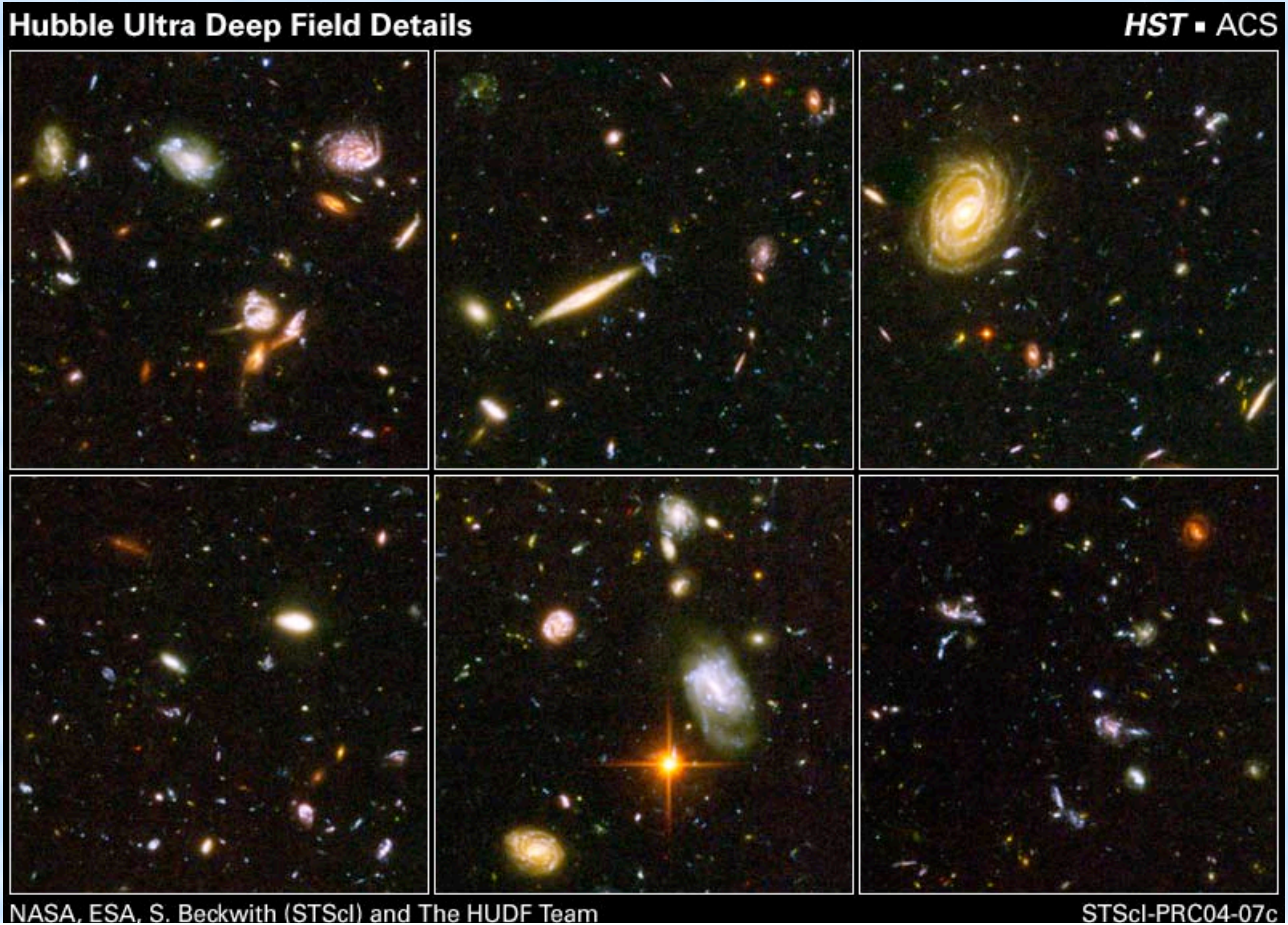


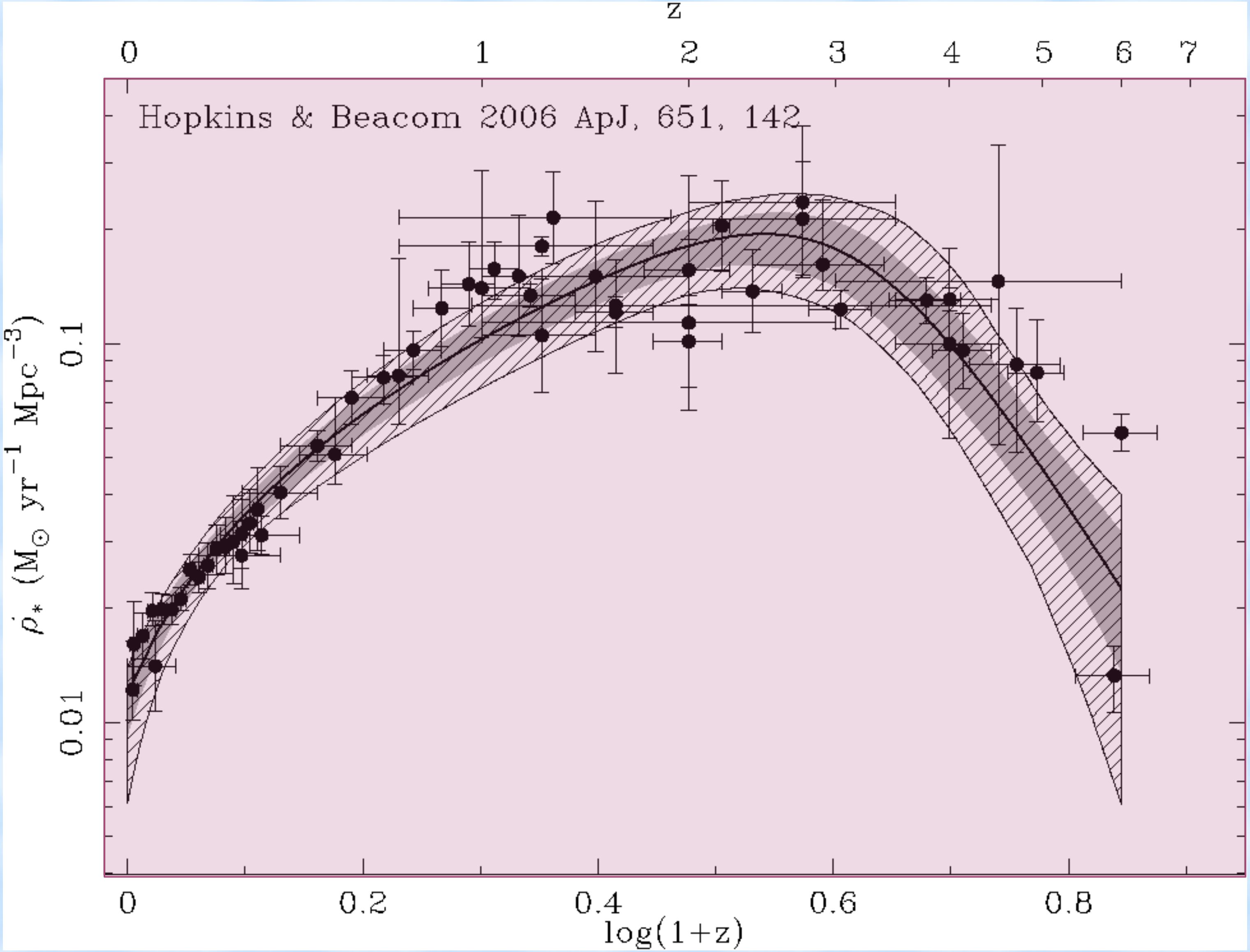


http://www.astro.princeton.edu/~frei/Gcat_htm/poster.jpg


Hubble Ultra Deep Field Details
HST ▪ ACS
NASA, ESA, S. Beckwith (STScI) and The HUDF Team
STScI-PRC04-07c

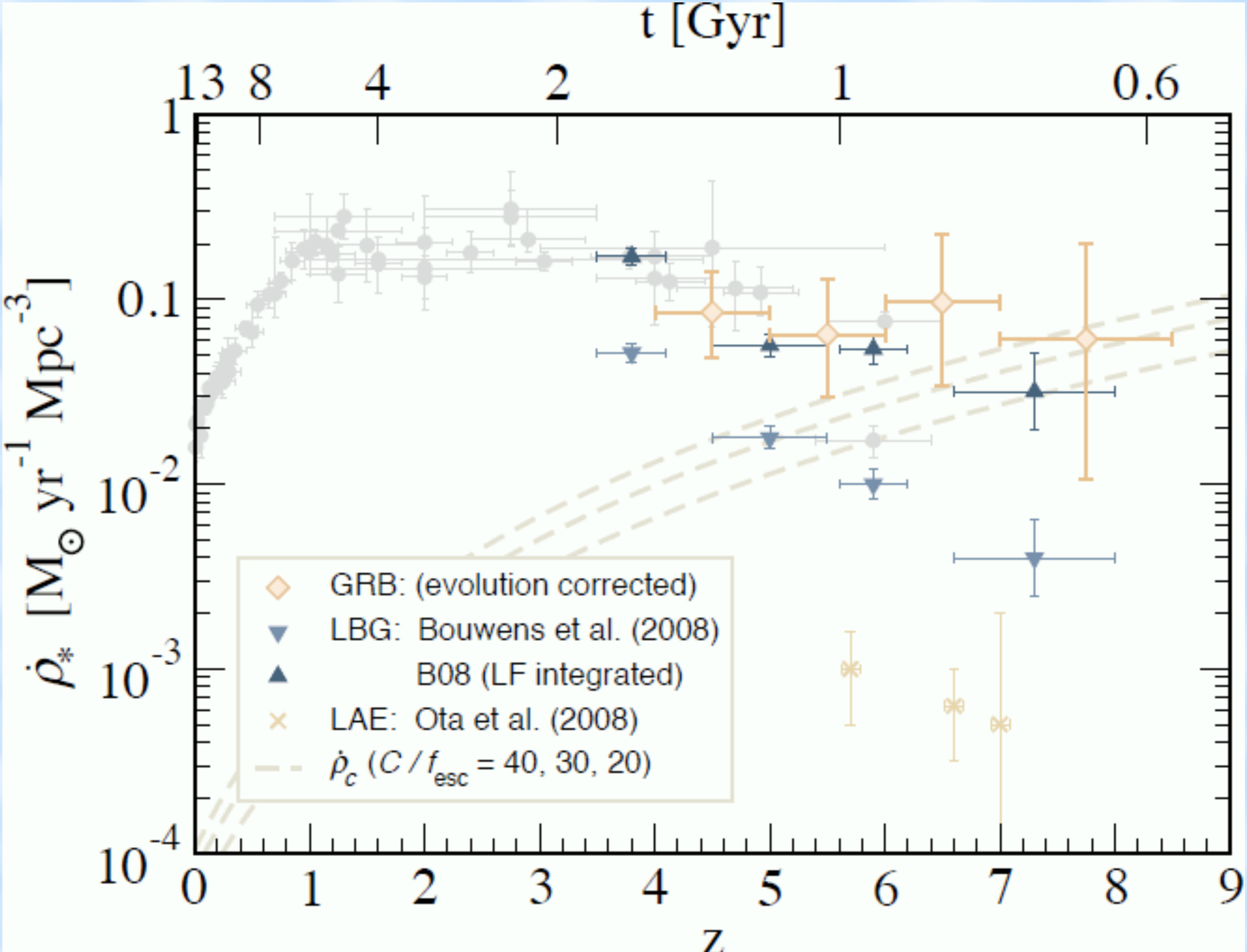
Comoving space density of SFR

SFR density



Redshift

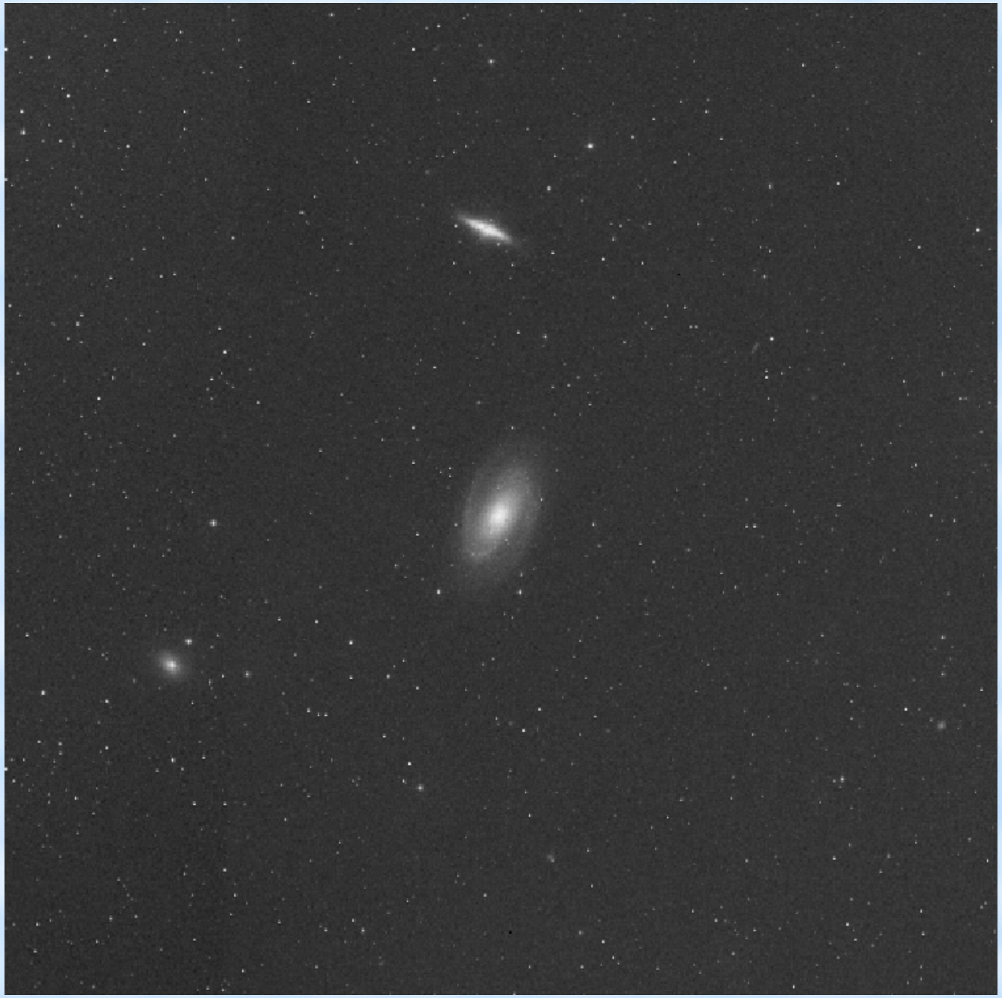
Comoving space density of SFR



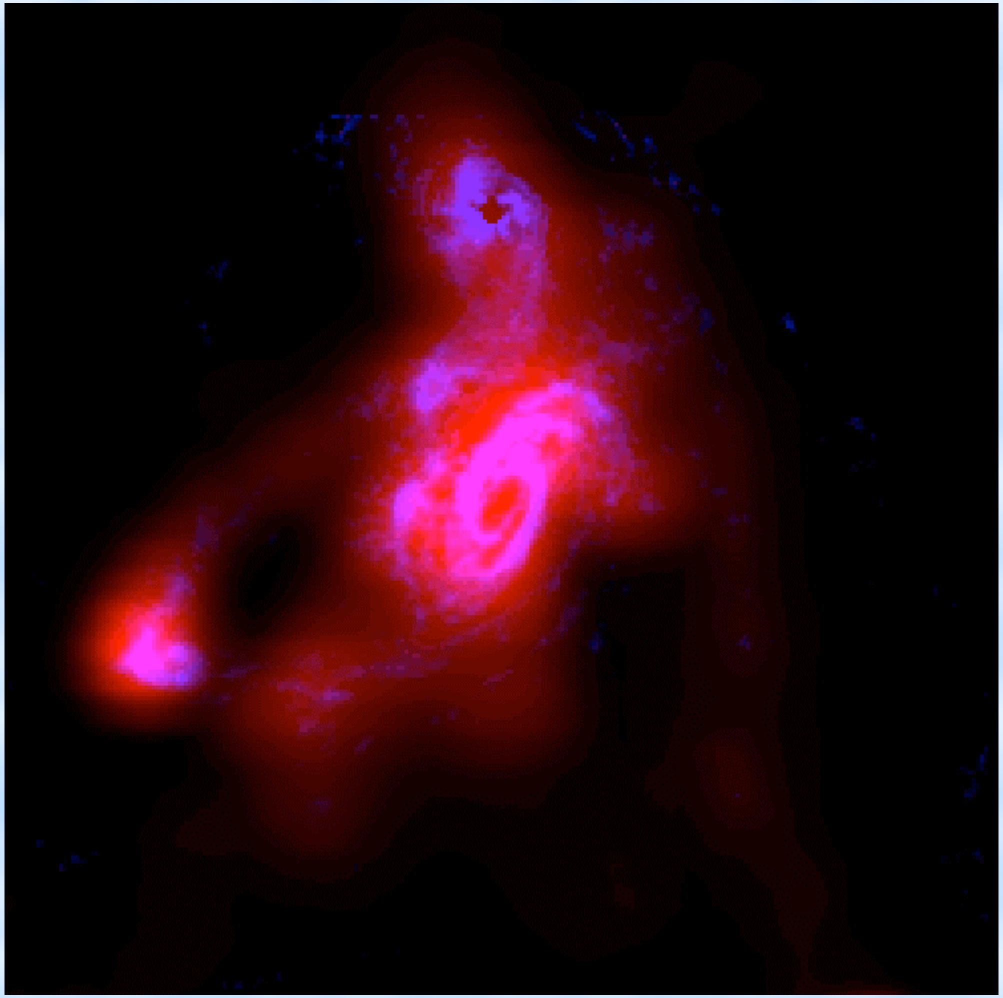
SFR density

Redshift

Why is gas important?



Stars

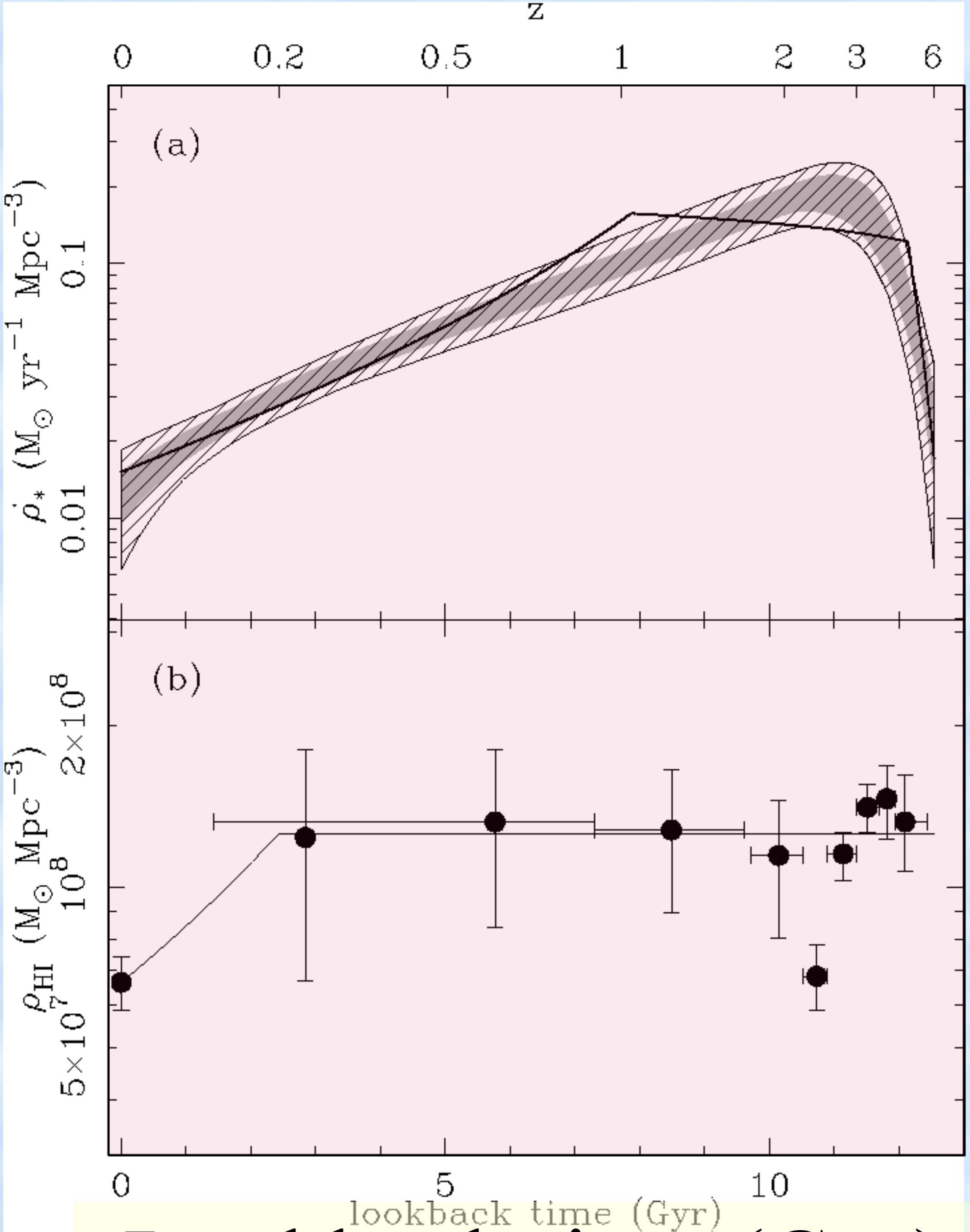


Gas

M81 galaxy group

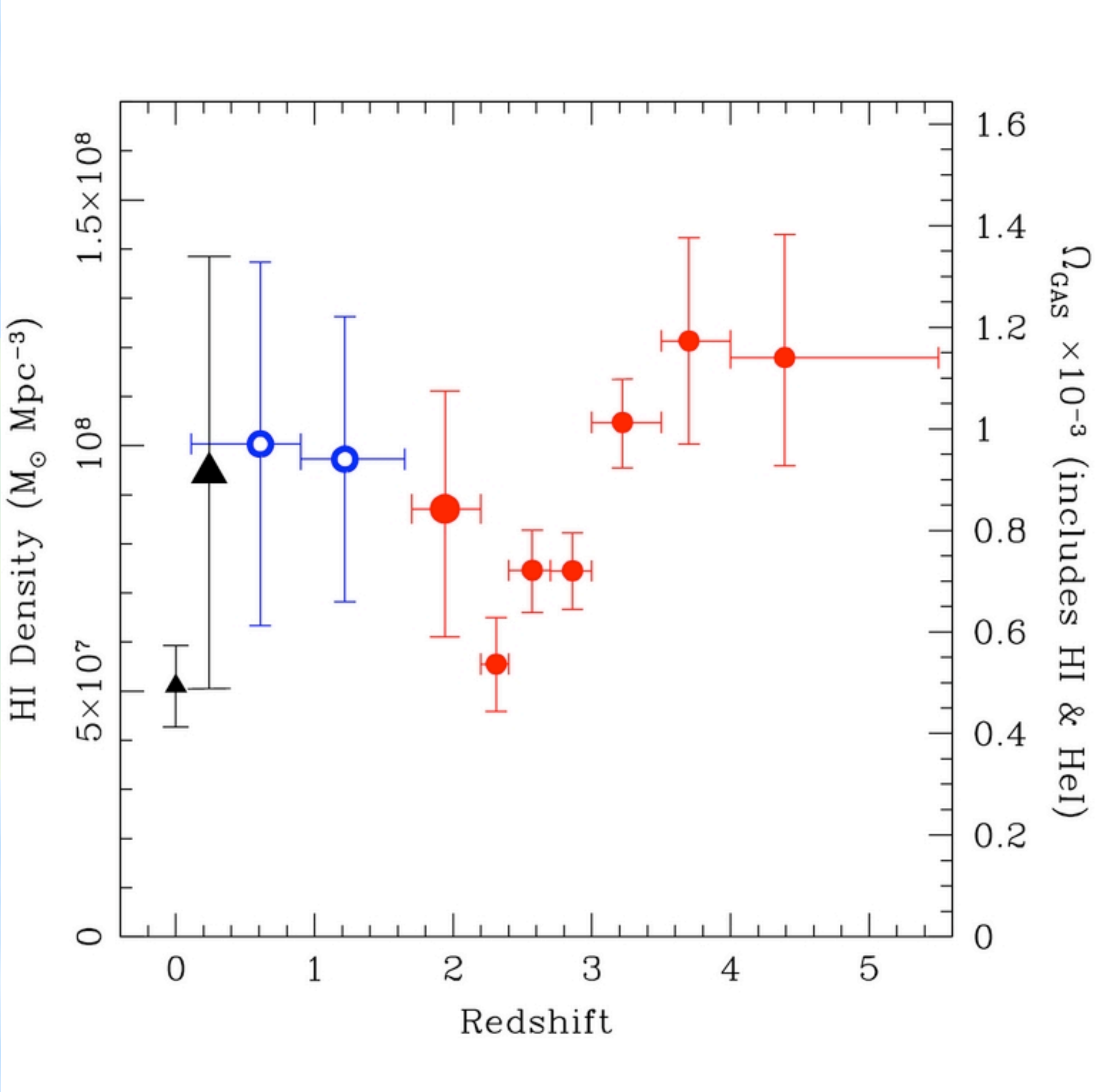
SFR density

HI density



Lookback time (Gyr)

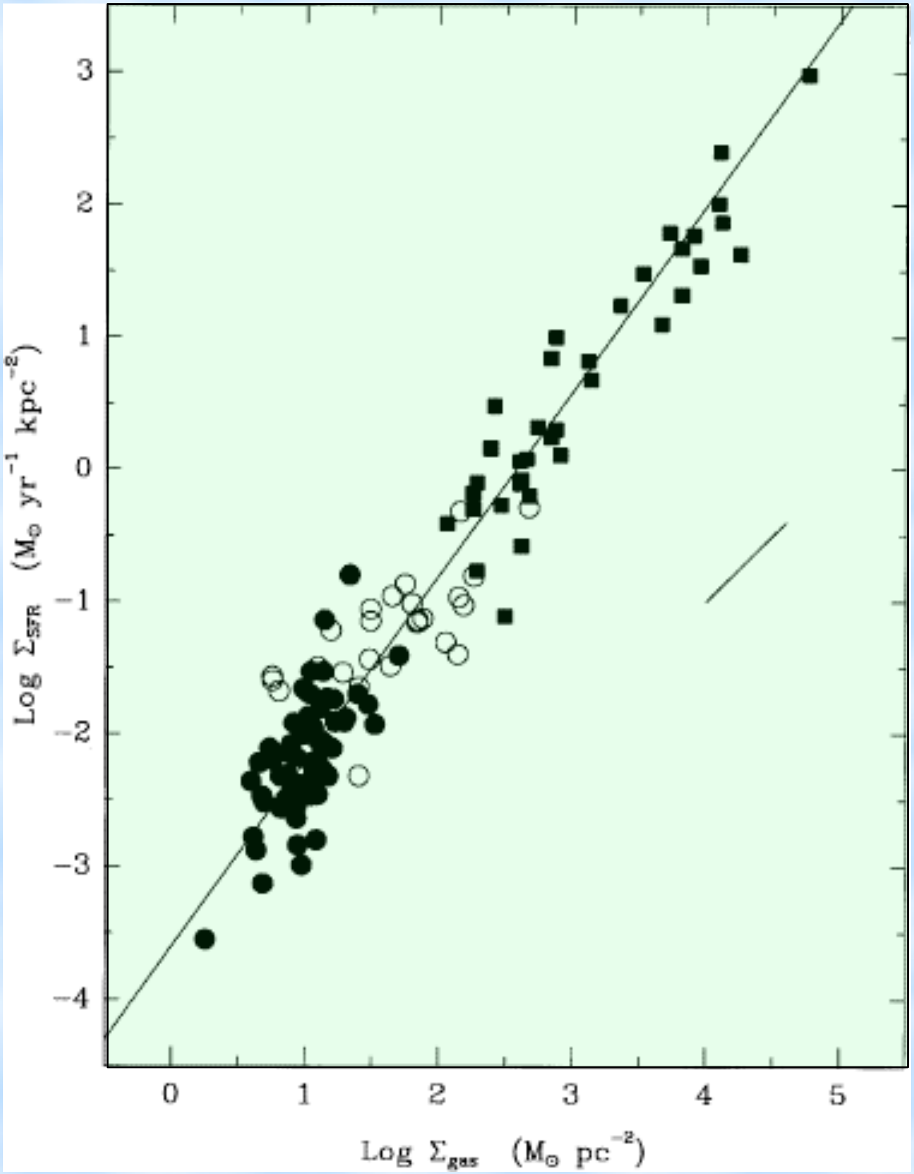
HI density



Redshift

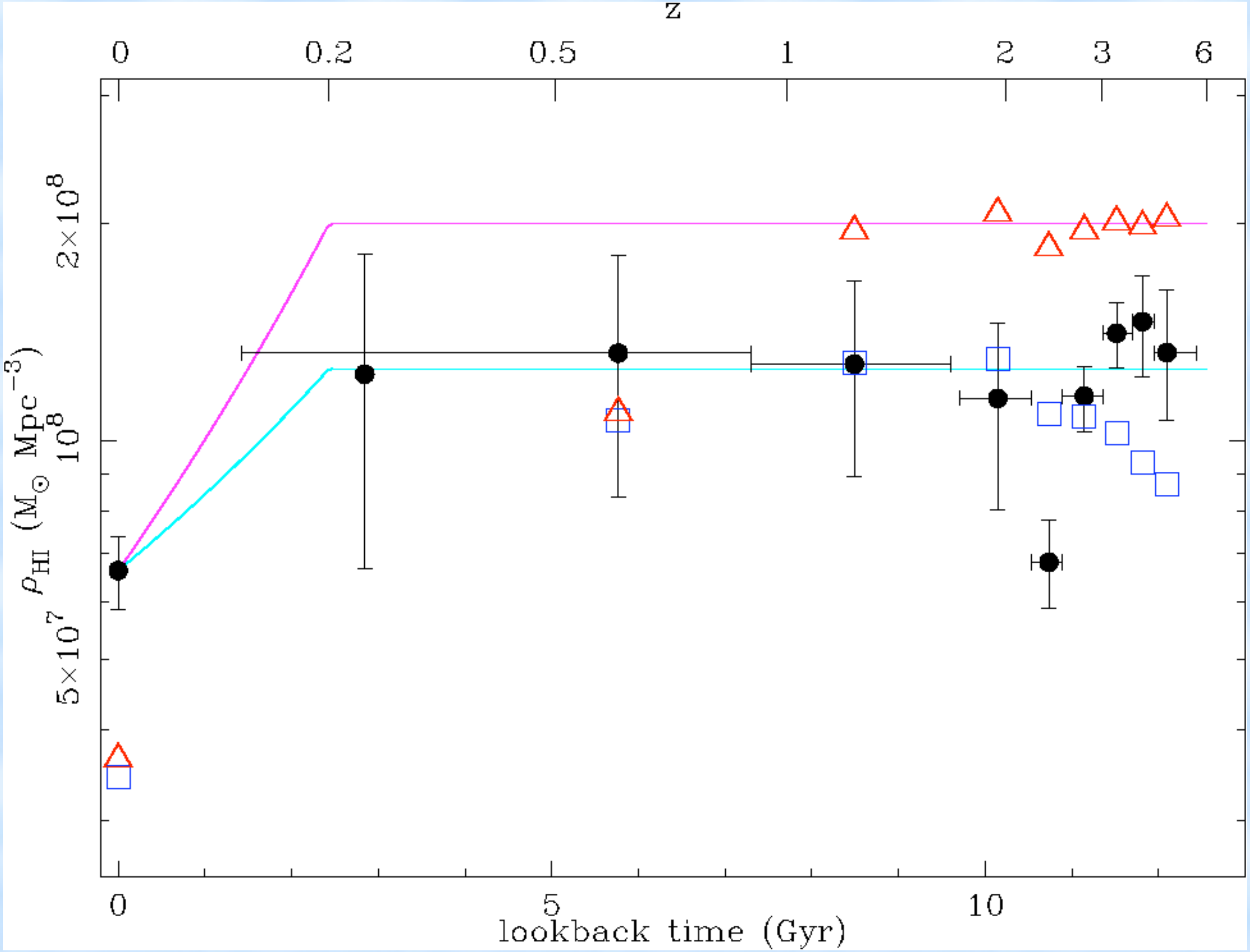
Kennicutt-Schmidt law of star formation

SFR surface density



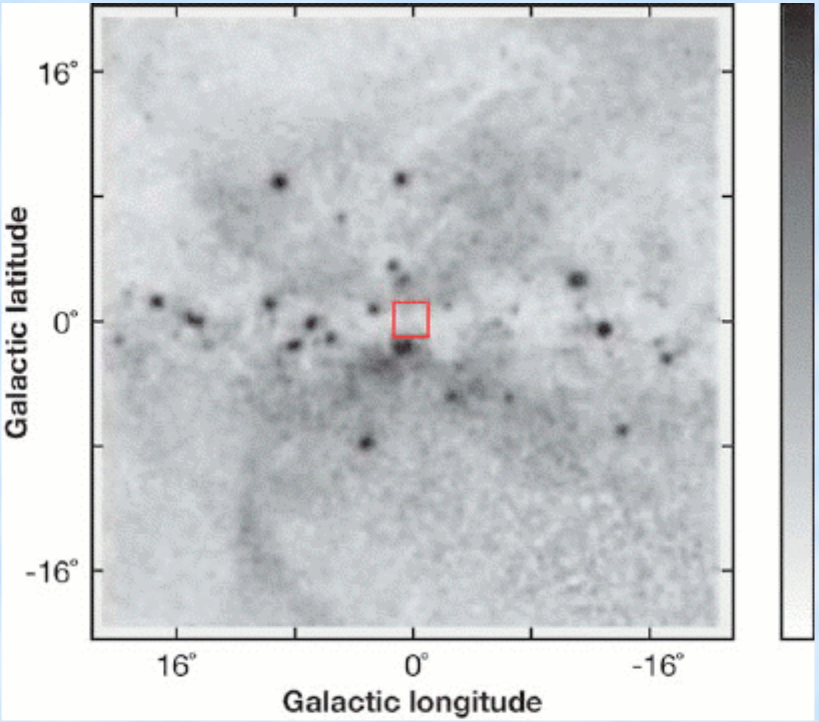
gas surface density

The “star forming” gas



Hopkins, McClure-Griffiths & Gaensler
2008, ApJ, 682, L13

Galactic Winds



X-ray

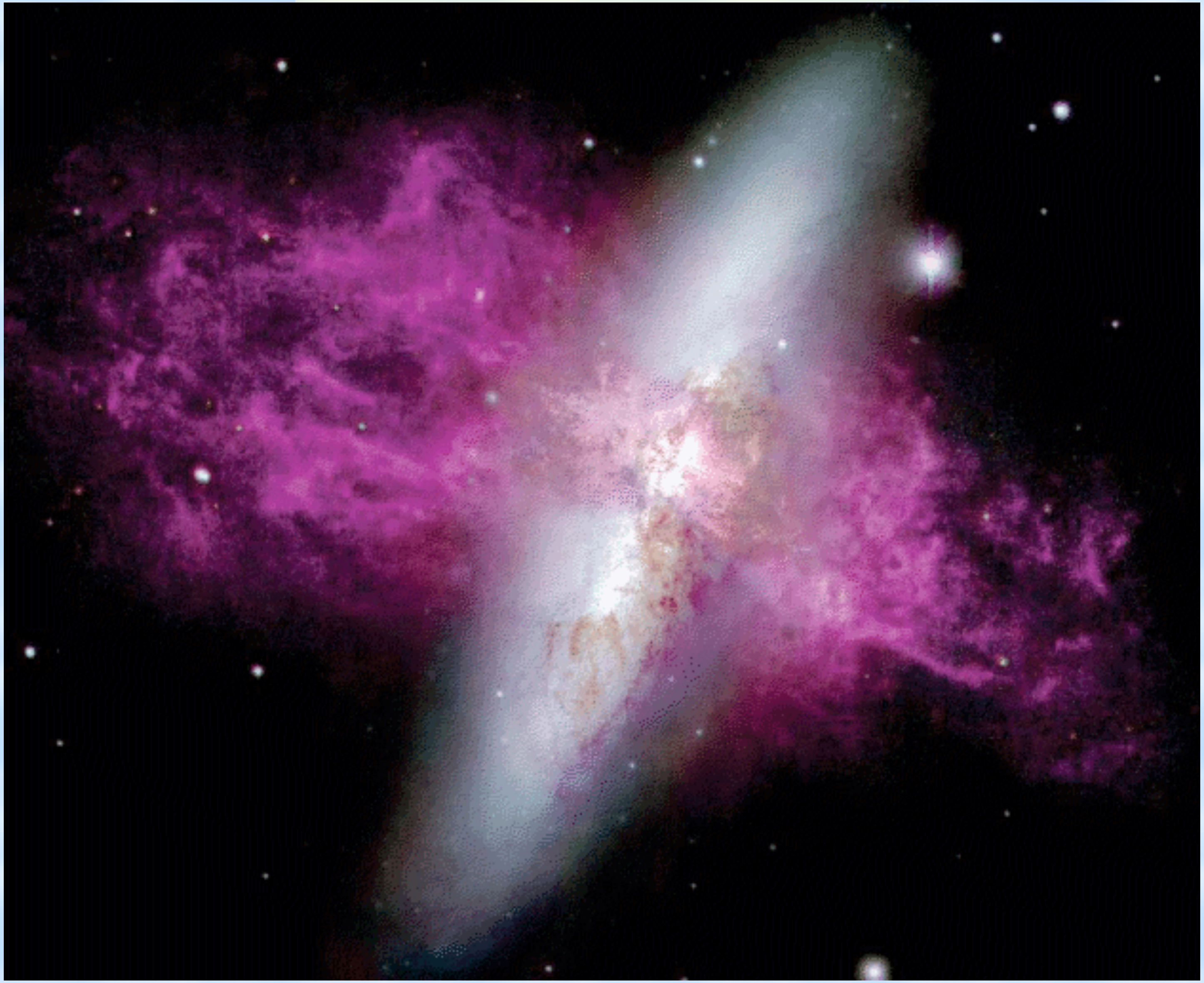
Bland-Hawthorn & Cohen
2003, ApJ, 582, 246

Mid-IR

Veilleux, Cecil, Bland-Hawthorn
2005, ARAA, 43, 769

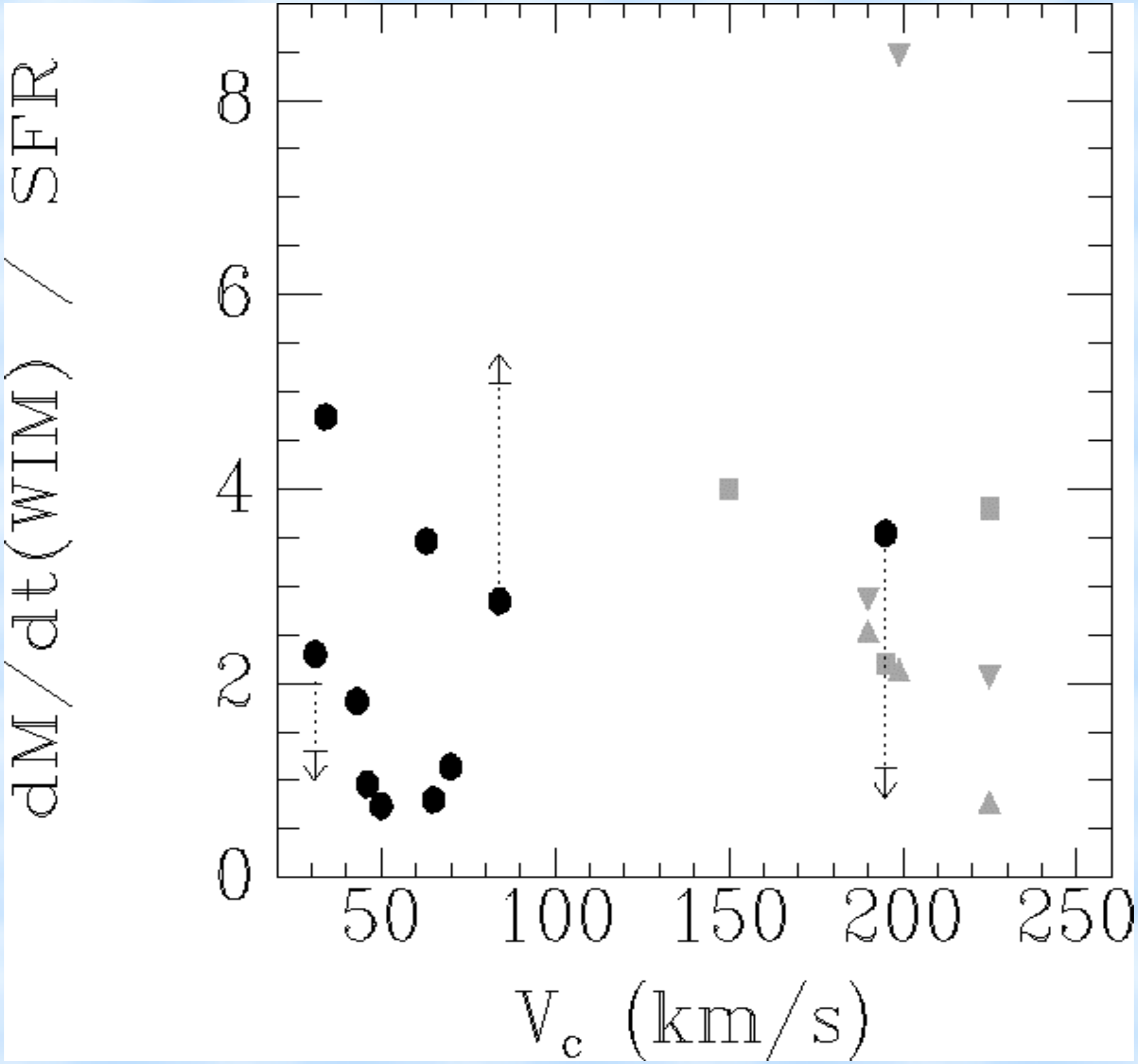
The Milky Way wind

Galactic Winds



The M82 wind

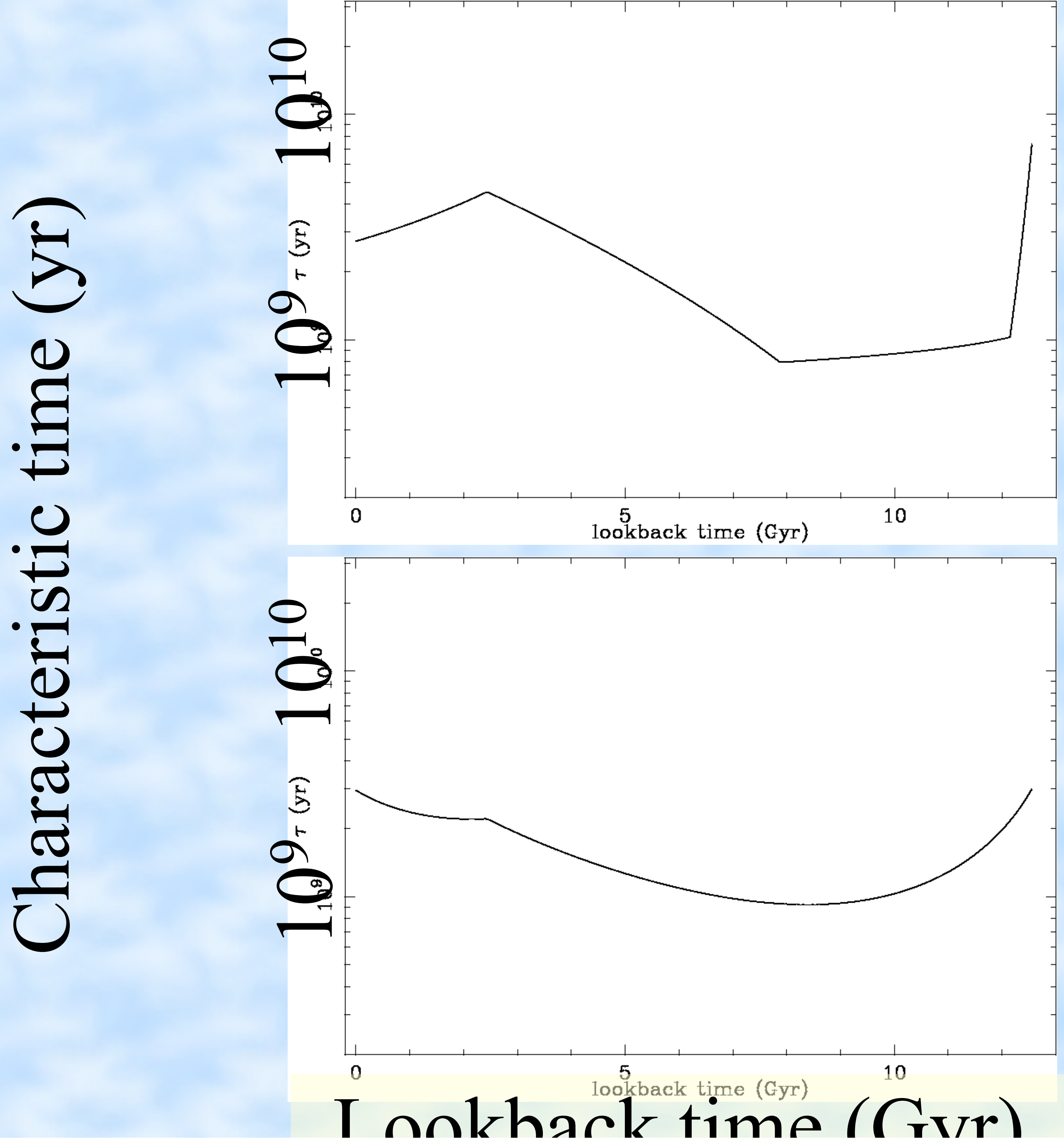
Mass loss in winds



Martin 1999, ApJ, 513, 156

Timescale for gas consumption

- Divide gas mass density by:
  - star formation rate density,
  - minus gas returned through recycling,
  - plus extra factor for “consumption” by galactic winds.
- Timescale is **1-5 Gyr** at all redshifts. Especially at high-z where SFR is high, timescale is 1 Gyr. Gas reservoir rapidly consumed.
- Consistent with timescales within nearby galaxies.



Characteristic time (yr)
10^10
10^9
τ (yr)
0
5
10
lookback time (Gyr)
Lookback time (Gyr)

Modelling the evolution of the star forming gas

Gas lost through:

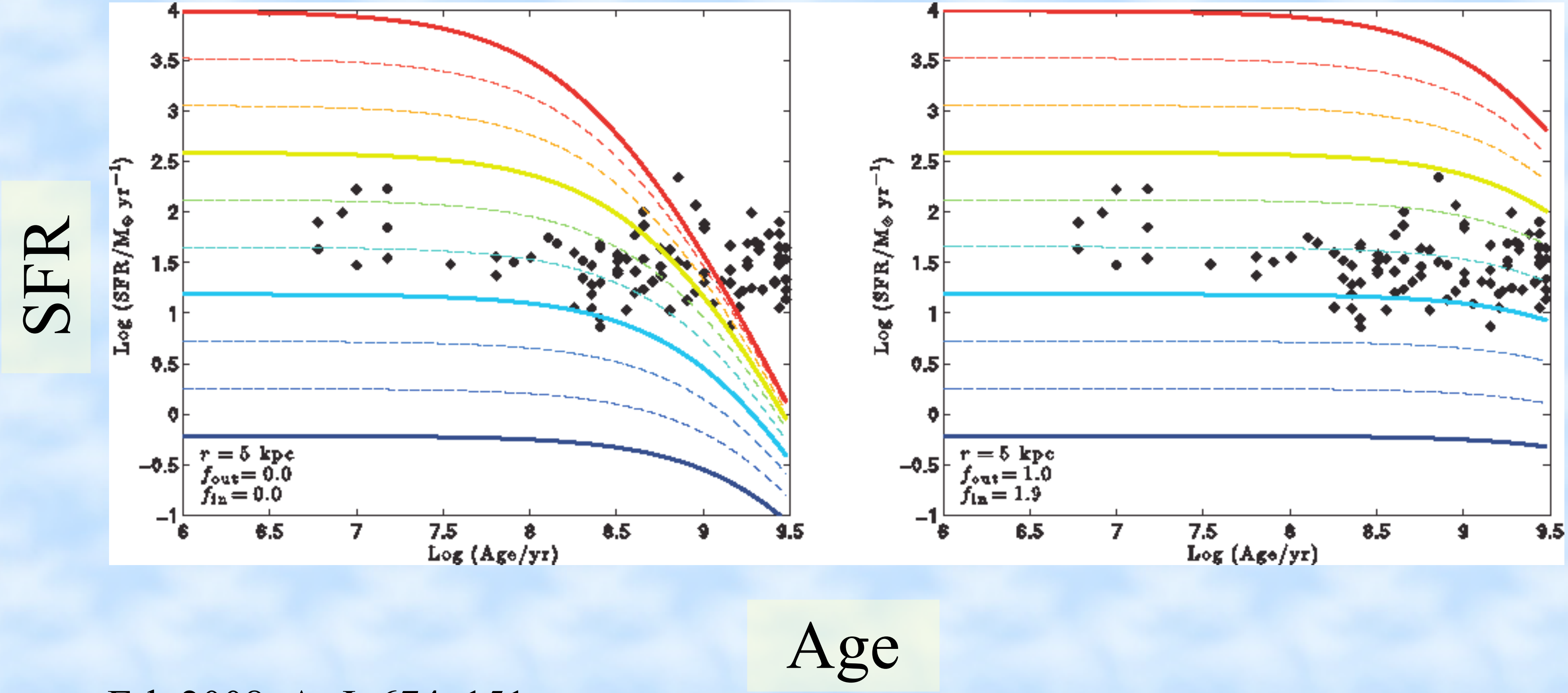
- Star formation
- Winds

Gas replenished through:

- Recycling (supernova ejecta, stellar winds)
- Infall
- Cooling and recombination of ionised gas

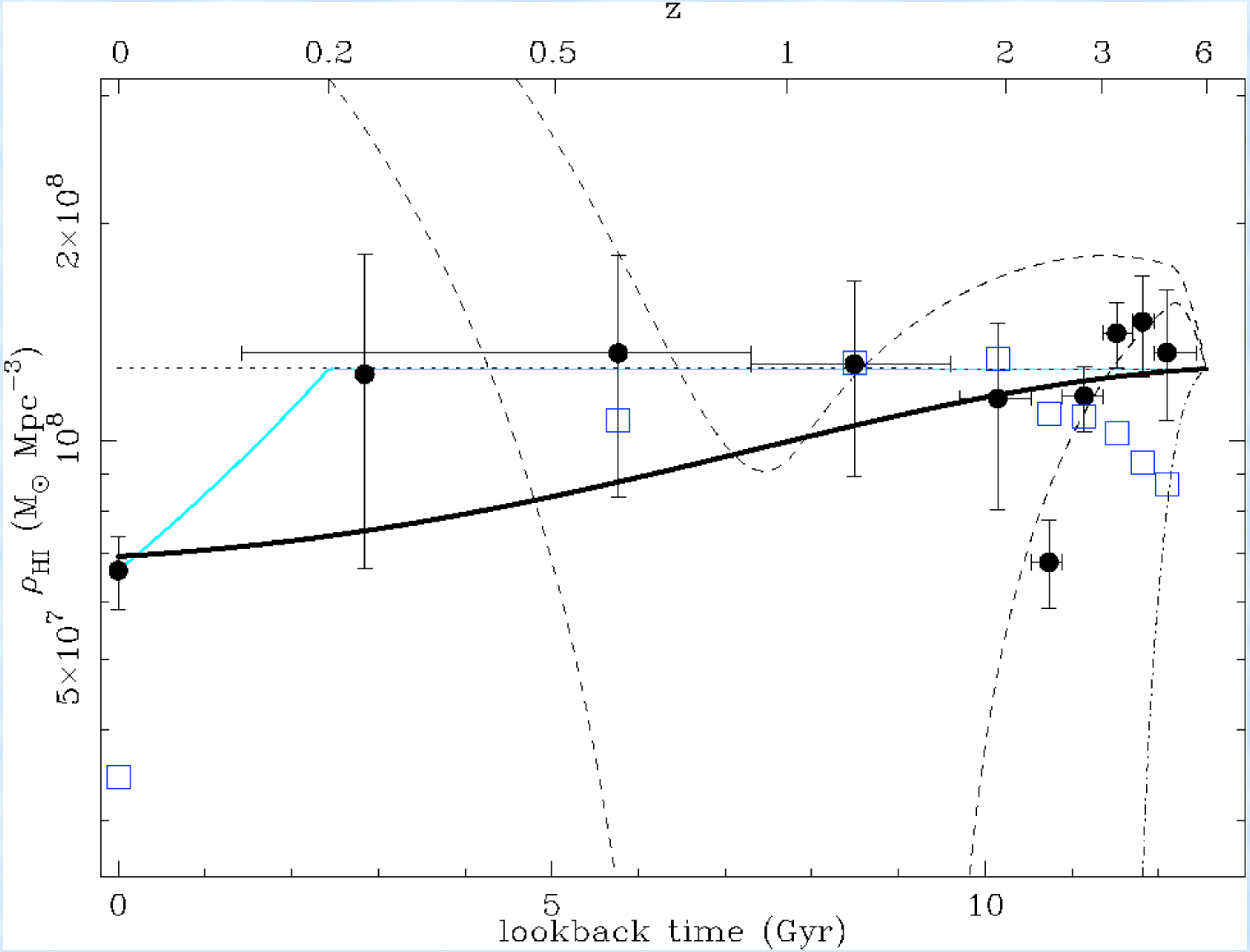
$$\rho_{\mathrm{SFG}}(t_{\mathrm{L}}) = \rho_{\mathrm{SFG}}(t = 12.55) + \int_{t=12.55}^{t=t_{\mathrm{L}}} (-1.6\dot{\rho}_*(t) + K(t))\, dt.$$

SFR of z~2 galaxies as a function of age



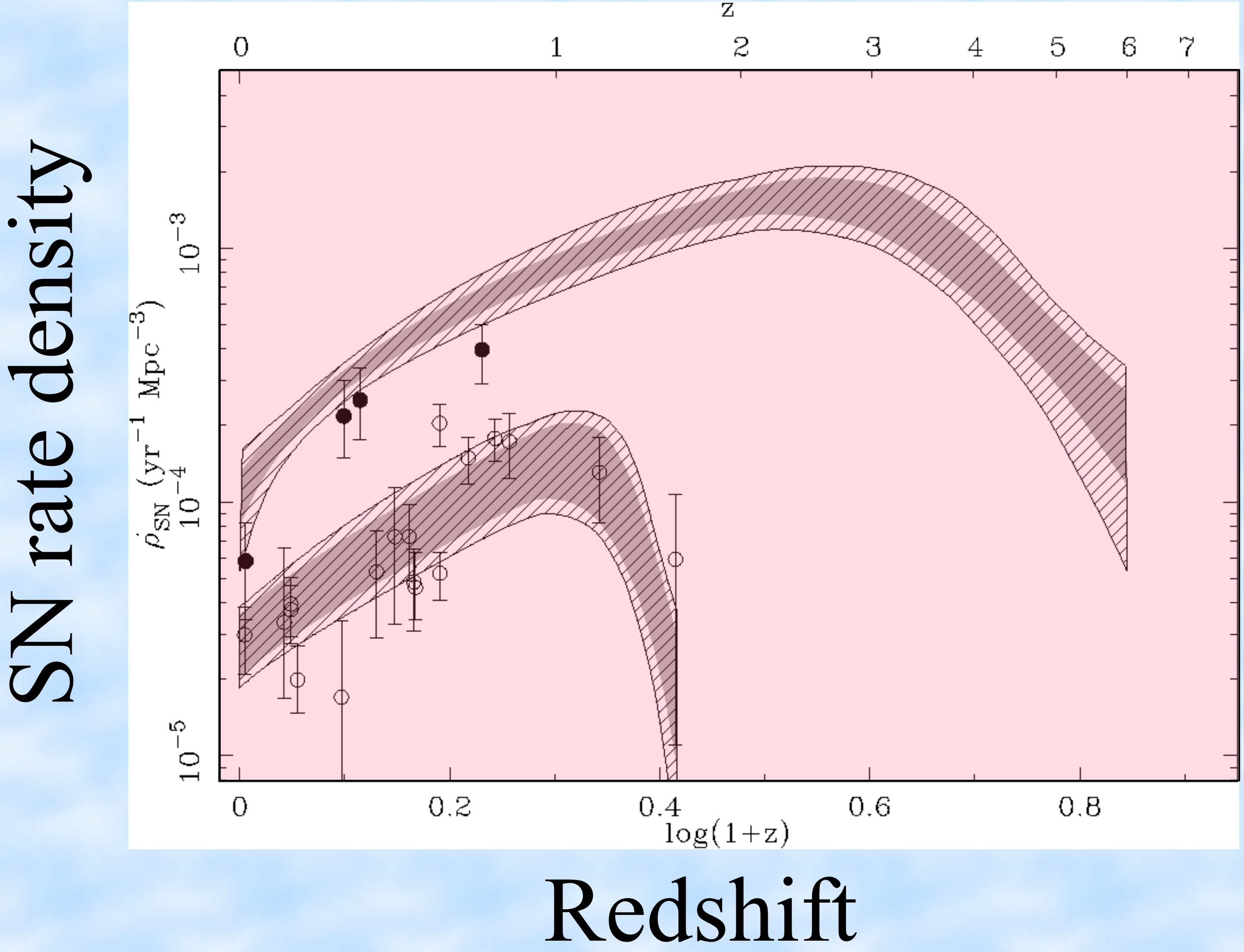
Erb 2008, ApJ, 674, 151

Evolution of star forming gas



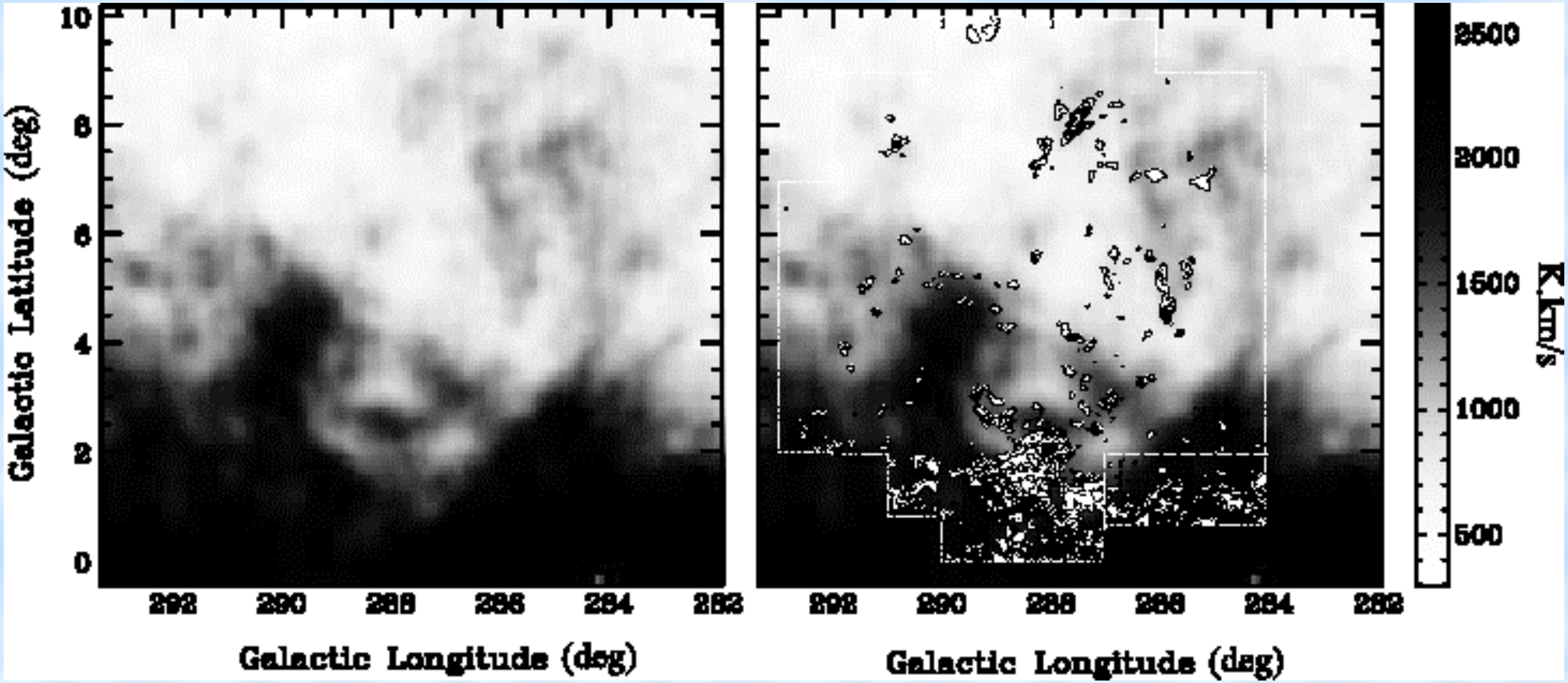
Hopkins, McClure-Griffiths & Gaensler
2008, ApJ, 682, L13

SFH is directly related to SN rate density



Hopkins & Beacom, 2006, ApJ, 651, 142

The GSH 287+04-17 (“Carina Flare”) Supershell



Dawson et al. 2008, MNRAS, 387, 31

How much supershell replenishment?

Replenishment rates required by supernovae:
~**100-200 $M_\odot$** per SN event (if *every* SN contributes)

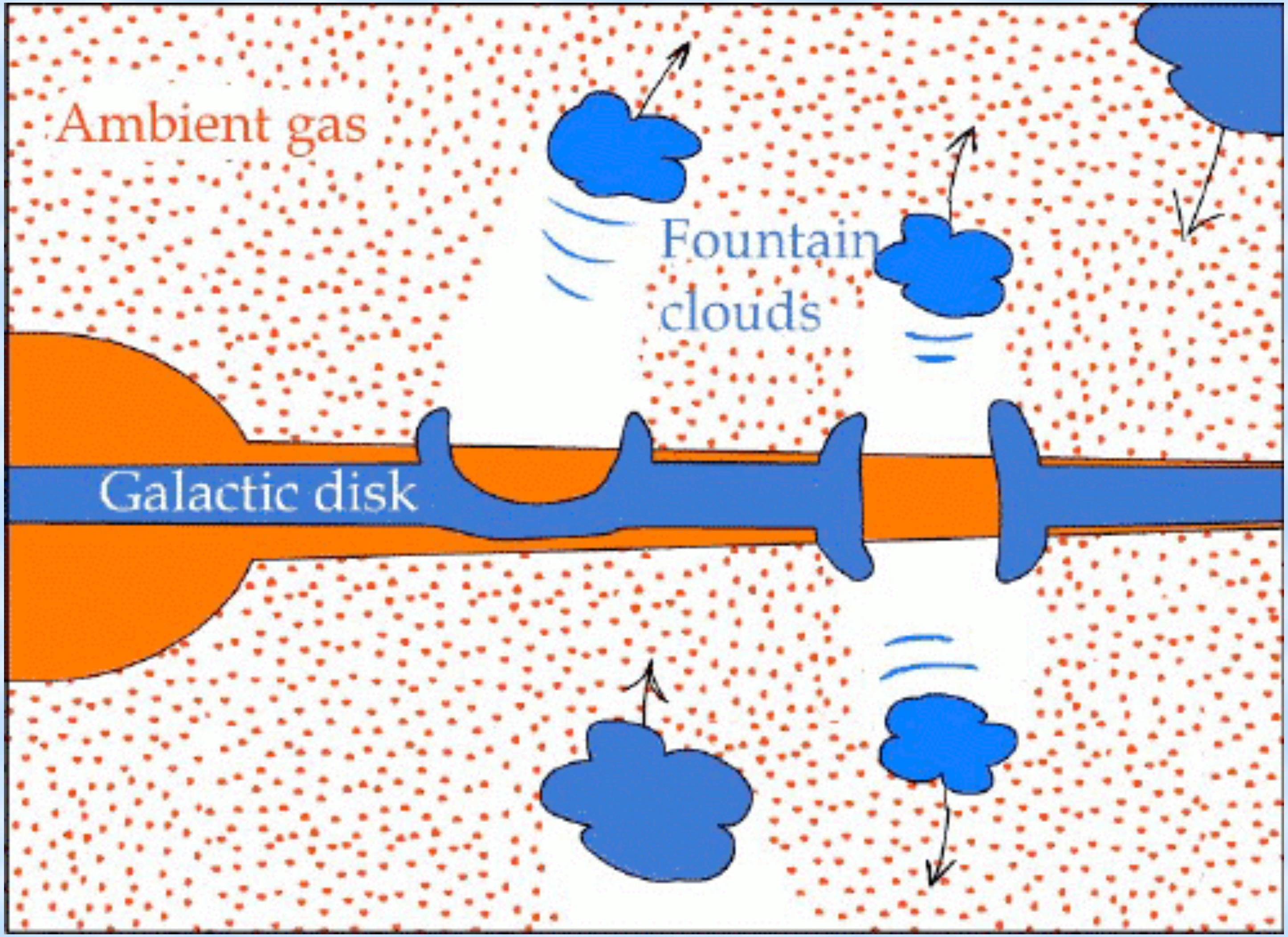
In the GSH 287+04-17 supershell, up to 4×10^4 $M_\odot$ cooled and recombined. Supershell estimated to have required 30 stars >7 $M_\odot$ to form.

Replenishment achievable through supershells:
~**1300-2000 $M_\odot$** per SN event

Limitations and future directions

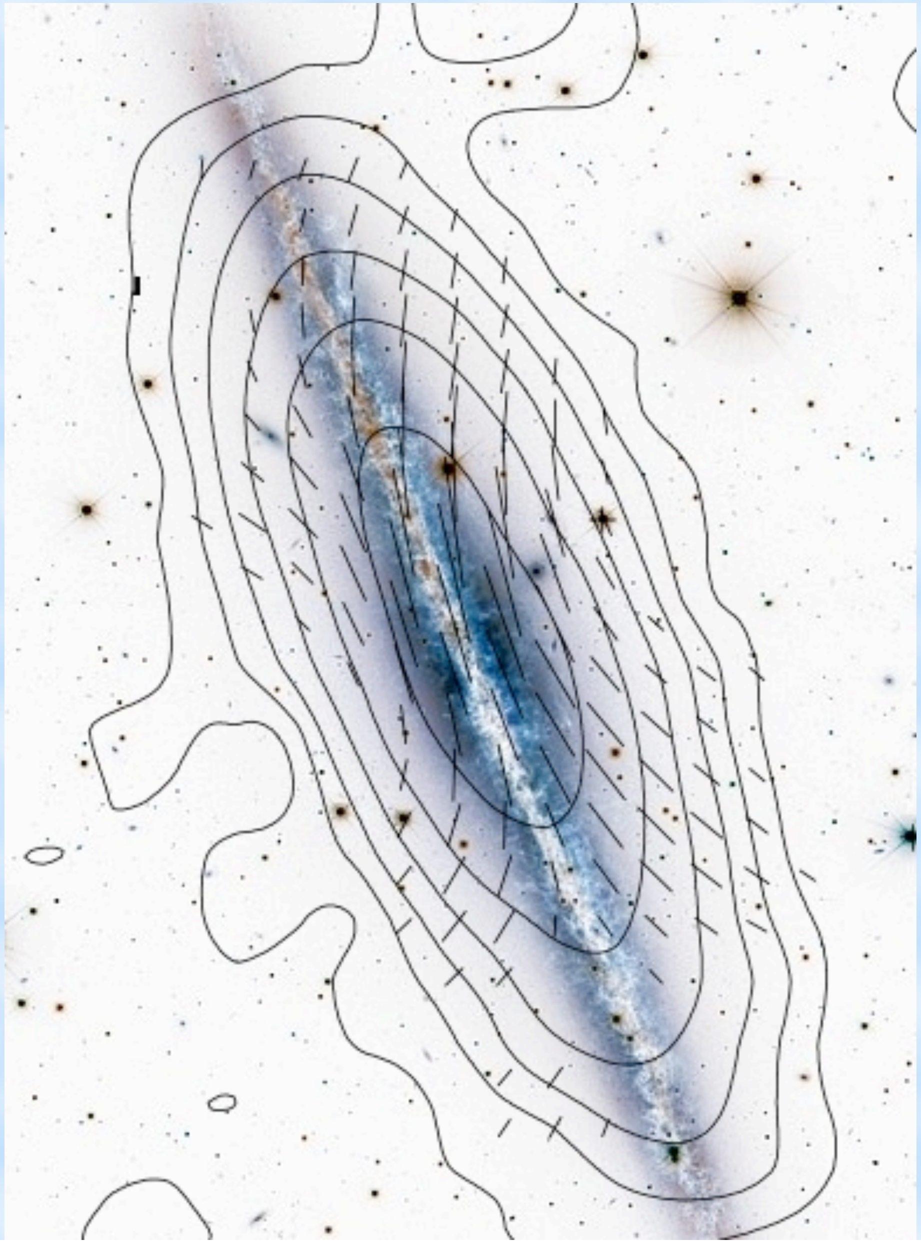
- What is the consequence of different galaxy types dominating the star formation history at different redshifts?
- Where is the location of the ionised reservoir? Already within the disk? In a local halo? In an extended halo?
- If the reservoir is not within the disk, what is the infall mechanism?

Boosting infall rates



Fraternali 2008, in "The galaxy disk in cosmological context" (arXiv:0807.3365)
See also Fraternali and Binney, 2008, MNRAS 386, 935

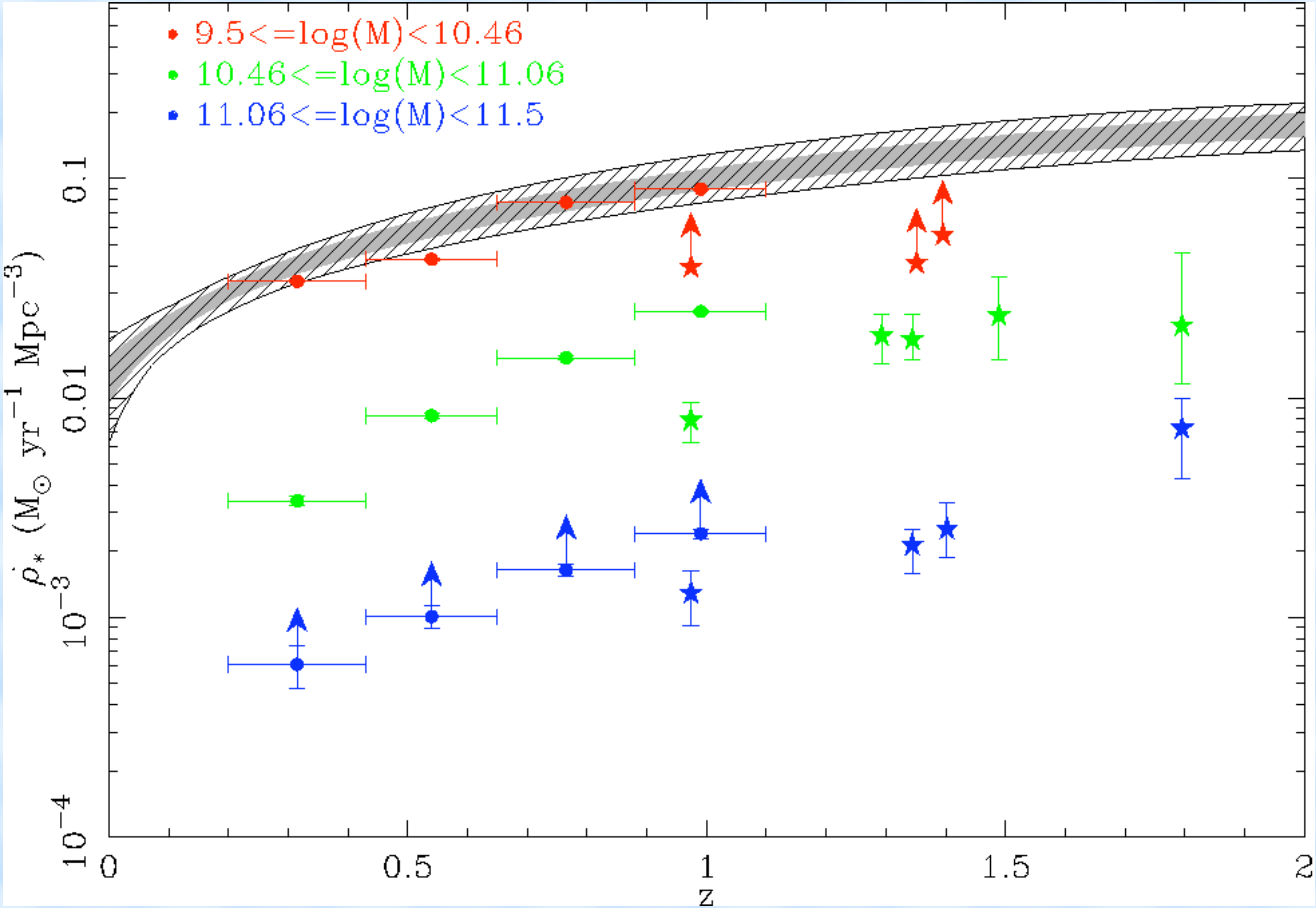
Magnetic fields as an infall mechanism



Total radio emission and B-vectors of the edge-on spiral galaxy NGC 891 (84” resolution), observed at 3.6 cm wavelength with the Effelsberg telescope (Krause 2008). The background optical image is from the CFHT (Copyright: MPIfR Bonn and CFHT/Coelum).

Thanks to Rainer Beck for providing this f

The mass-dependence of the SFH

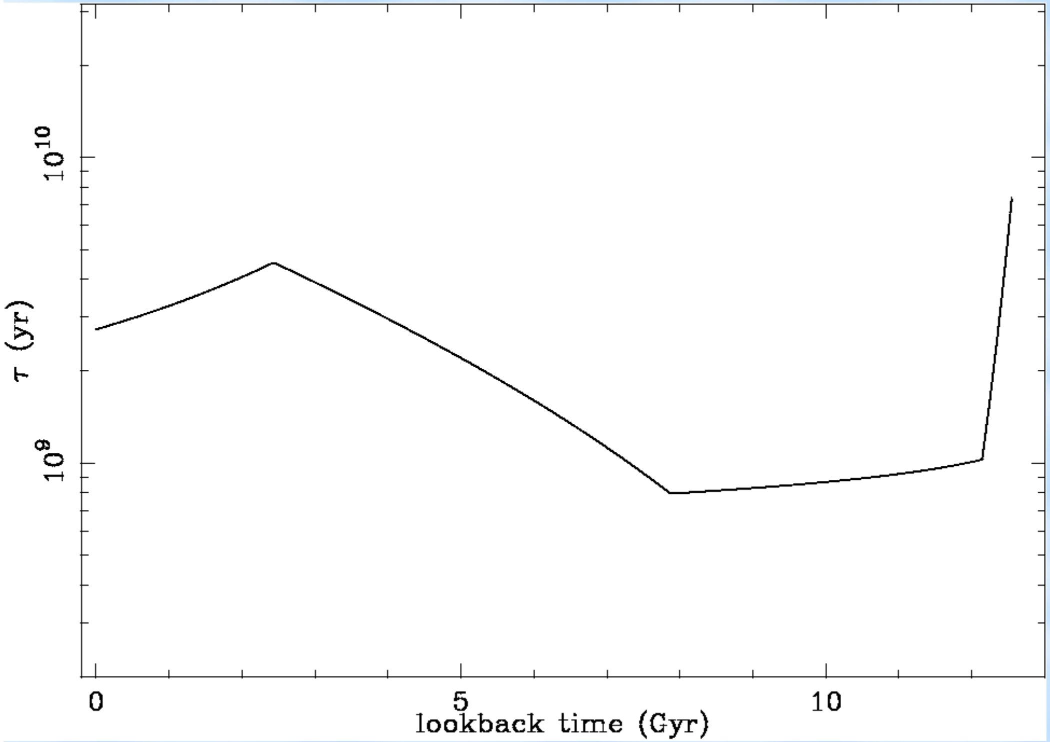


Adapted from Mobasher et al., 2009, ApJ 690, 1074

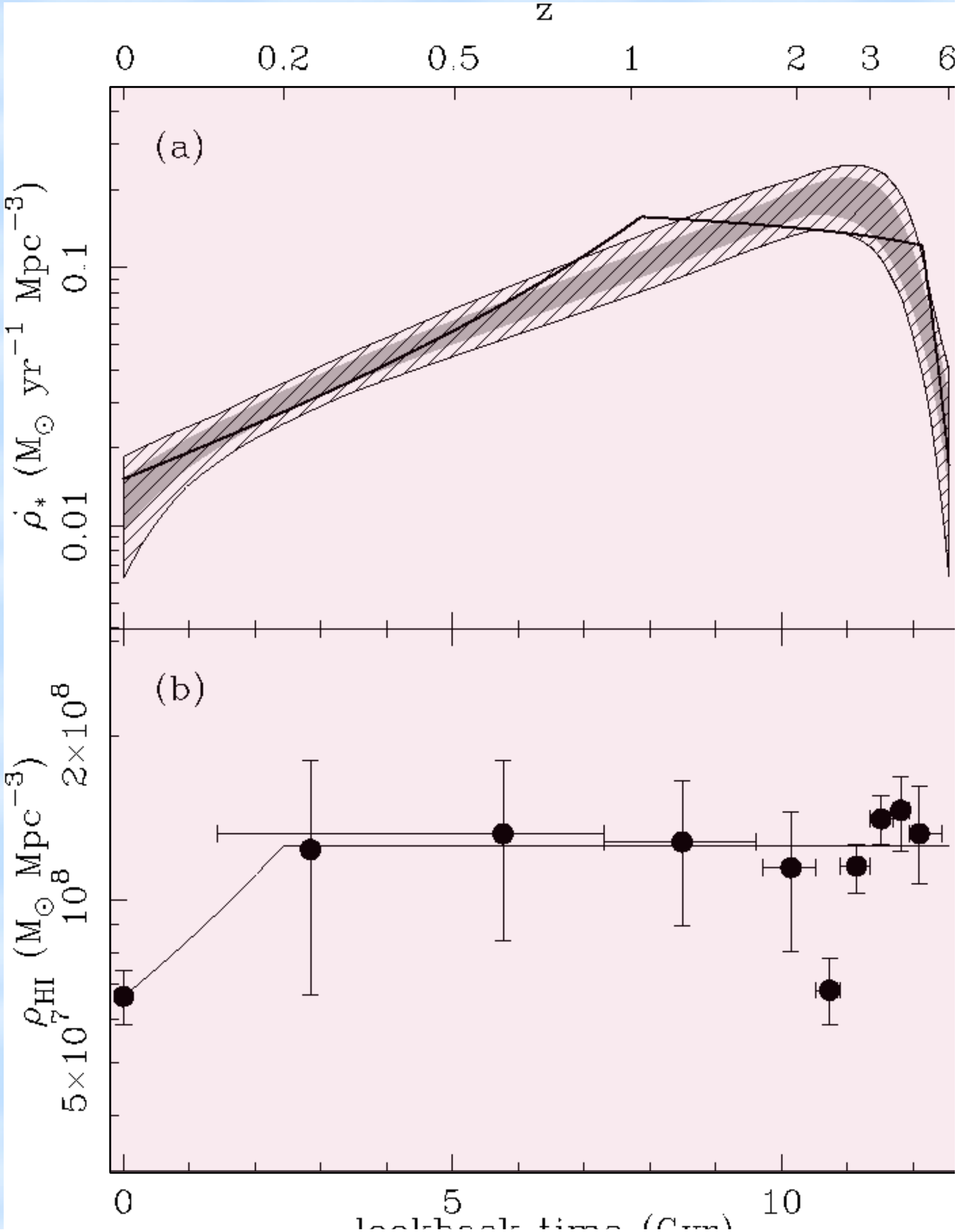
How is the HI distributed amongst galaxies?

- At one extreme we can assume that it is distributed evenly, or proportionally (by mass), between galaxies. This leads to the question of replenishment for all galaxies, at all redshifts.
- At another extreme we could assume that the difficulty of replenishment is perhaps a driver in cosmic downsizing:
  - At high-z assume all the HI is in the most massive galaxies, the ones possibly dominating the SFR density. They exhaust their gas in SF and winds in a Gyr or so, without replenishment, and their SF turns off.
  - Meanwhile lower-mass systems accumulate gas, and the HI at intermediate redshifts is primarily in these systems, which in turn exhaust their gas, and turn off.
  - At the lowest redshifts the HI is now primarily in the lowest mass systems, the ones currently dominating the SFH.
  - Now the question is not one of replenishment in individual galaxies, but of gas accretion onto progressively lower mass proto-galaxies.

Downsizing?



τ (yr)
10^{10}
10^9
0
5
10
lookback time (Gyr)



z
0
0.2
0.5
1
2
3
6
(a)
$\dot{\rho}_*$ ($M_\odot$ yr^{-1} Mpc^{-3})
0.1
0.01
(b)
ρ_{HI} ($M_\odot$ Mpc^{-3})
2×10^8
10^8
5×10^7
0
5
10

Summary

- The cosmic evolution of star formation is dramatically different from the cosmic evolution of gas in galaxies.
- If the gas is distributed amongst all galaxies at all redshifts, it must be replenished, and at a rate more or less proportional to the star formation rate, to maintain the slow evolution in the gas content of galaxies.
- Supershells are a possible, perhaps likely, mechanism to contribute the necessary replenishment:
  - They have the appropriate relation to the SFR (SNe), and
  - they can replenish gas at a sufficient rate.
- Do we need a continuous infall of hot ionised gas in all galaxies, or is it a question of gas accreting most efficiently on progressively lower-mass galaxies with decreasing redshift?