Gas and star-formation in galaxies over cosmic history

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Comoving space density of SFR

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SFR density

Redshift

$\rho_\star^* [M_\odot \text{yr}^{-1} \text{Mpc}^{-3}]$

$\dot{\rho}_c (C/f_{\text{esc}} = 40, 30, 20)$

GRB: (evolution corrected)
LBG: Bouwens et al. (2008)
B08 (LF integrated)
LAE: Ota et al. (2008)

Why is gas important?

Stars

M81 galaxy group

Gas

Thanks to Katie Chynoweth for the individual fits images
SFR density

HI density
HI density

Redshift


HI Density ($M_\odot$ Mpc$^{-3}$)

$\Omega_{\text{HI}} \times 10^{-3}$ (includes HI & He)
Kennicutt-Schmidt law of star formation
The “star forming” gas

Hopkins, McClure-Griffiths & Gaensler
Galactic Winds

X-ray
Bland-Hawthorn & Cohen

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

The Milky Way wind
Galactic Winds

The M82 wind
Mass loss in winds

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.
Lookback time (Gyr) vs. Characteristic time (yr)
Gas lost through:
- Star formation
- Winds

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

$$\rho_{SFG}(t_L) = \rho_{SFG}(t = 12.55) + \int_{t=12.55}^{t=t_L} (-1.6\dot{\rho}_*(t) + K(t)) \, dt.$$
SFR of $z \sim 2$ galaxies as a function of age

Evolution of star forming gas

Hopkins, McClure-Griffiths & Gaensler
SFH is directly related to SN rate density

Redshift

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

How much supershell replenishment?

Replenishment rates required by supernovae:
$\sim 100-200 \text{ M}_\odot$ per SN event (if every SN contributes)

In the GSH 287+04-17 supershell, up to $4 \times 10^4 \text{ M}_\odot$ cooled and recombined. Supershell estimated to have required 30 stars $>7 \text{ M}_\odot$ to form.

Replenishment achievable through supershells:
$\sim 1300-2000 \text{ M}_\odot$ 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

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 figure.
The mass-dependence of the SFH

- $9.5 \leq \log(M) < 10.46$
- $10.46 \leq \log(M) < 11.06$
- $11.06 \leq \log(M) < 11.5$

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?
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?