Star formation and gas supply

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Galaxy evolution in a bathtub

Still a lot of work to do to understand how gas cycles in and out of galaxies

see also, e.g. Bouche’ et al. (2010), Dave’ et al (2011, 2012), Krumholz & Dekel (2012)
Star formation cycle

Need large representative sample with homogeneously measured gas content (atomic and molecular) and SFR
Cold gas surveys of massive galaxies

**GASS: the GALEX Arecibo SDSS Survey**

Arecibo large program: 1005 hrs, 760 galaxies (Catinella et al. 2010, 2013). Selection:

- $0.025 < z < 0.05, \ 10 < \log M_*/M_\odot < 11.5$
- Gas fraction limited: $M_{\text{HI}}/M_* > 1.5\%$

**COLD GASS: CO Legacy Database for GASS**

IRAM large program: ~500 hrs (Saintonge et al. 2011)

- Unbiased sample of 350 galaxies randomly selected from GASS
- Gas fraction-limited; additional offset pointings when necessary

Both surveys now extended to $\log M_*/M_\odot = 9$
Gas scaling relations

Catinella et al. 2013 + in prep., Saintonge et al. 2011
Dissecting the SFR-stellar mass plane

\[ \text{sSFR} = \frac{\text{SFR}}{M_*} = \frac{M_{\text{HI}}}{M_*} \frac{M_{\text{H}_2}}{M_{\text{HI}}} \frac{\text{SFR}}{M_{\text{H}_2}} = f_{\text{HI}} R_{\text{mol}} \text{SFE}_{\text{H}_2} \]

reference: SSFR~0.1 Gyr\(^{-1}\)

Saintonge, Catinella et al. subm.
Atomic hydrogen

HI content varies mostly **across**, but also **along** reference sequence (RS).

HI alone cannot explain variation of sSFR (lack of dyn range).

Saintonge, Catinella et al. subm.
Molecular hydrogen

\[ f_{\text{H}_2} = \frac{M_{\text{HI}}}{M_\star} = \frac{M_{\text{H}_2}}{M_{\text{HI}}} = f_{\text{HI}} \ R_{\text{mol}} \]

- H$_2$ content varies almost only across RS
- H$_2$ alone cannot explain variation of sSFR

Saintonge, Catinella et al. subm.
SFE is not constant

\[ t_{\text{DEP}} = \frac{M_{\text{H}_2}}{\text{SFR}} = \frac{1}{\text{SFE}} \]

Saintonge et al. 2011
Molecular-to-atomic hydrogen ratio

Saintonge, Catinella et al. subm.

$H_2/\text{HI}$ content varies **along** RS (on the RS, from 25% to >70%!!)
Cold gas in the SFR-stellar mass plane

sSFR = \frac{SFR}{M^\star} = f_{HI} \cdot R_{mol} \cdot SFE_{H2}

Position of galaxy in the SFR-M^\star plane depends on:

1. Amount of gas  
2. How much of it is available for SF  
3. SFE

Saintonge, Catinella et al. subm.
Cold gas in the SFR-stellar mass plane

\[ sSFR = \frac{SFR}{M^*} = f_{\text{HI}} \frac{R_{\text{mol}}}{SFE_{\text{H}_2}} \]

Position of galaxy in the SFR-M* plane depends on:

1. Amount of gas
2. How much of it is available for SF
3. SFE

Saintonge, Catinella et al. subm.
Main sequence of SF galaxies

Along the MS

- HI, H$_2$ fractions decrease
- SFE, H$_2$/HI ~ constant ($t_{\text{DEP}} \approx 1.3$ Gyr, $R_{\text{MOL}} \approx 0.3$)

Flattening of MS at $M_*/M_\odot > 10^{10}$ due to gradual decrease of total gas fraction of SF galaxies
Quenching “danger zone”

Very high H$_2$/HI >70%, total gas mass $\sim 10^{10}$ M$_\odot$, SFR$\sim 10$ M$_\odot$/yr $\rightarrow$ \textbf{w/in $\sim$1 Gyr of quenching!}

Unusual combination of bulge+young stellar populations in the central regions
HI excess galaxies: interesting population of galaxies with huge HI reservoirs that are not forming stars → outliers of $f_{\text{HI}}$ vs sSFR relation
GASS 3505: the HI excess prototype

SDSS

Geréb, Catinella et al. (subm.)

HI mass $\sim 10^{10}$ M$_\odot$

$M_{\text{HI}} / M_\star = 0.50$

$M_{\text{H}_2} / M_\star < 0.05$

SFR = 0.1 M$_\odot$/yr

Merger with unusually HI-rich dwarf reproduces main properties of HI disk

- Bigiel et al. (2010)
- GASS 3505
- Lemonias et al. (2014)
HI excess population
HI excess population

Large incidence of polar/misaligned disks ➔ was the huge HI reservoir accreted?
Summary

- Large, unbiased samples of galaxies with **atomic and molecular gas** measurements are key to understand galaxy evolution.

- Position of galaxy in the SFR-M\(^{\bullet}\) plane depends on:
  1. Amount of gas
  2. How much of it is available for SF
  3. Efficiency of the conversion of this gas into stars

- Flattening of SF main sequence: decrease of gas fractions, which is accompanied by bulge build up

- Interesting populations of galaxies about to run out of gas, or with huge gas reservoirs that are not forming stars
On the MS, as mass increases galaxies steadily consume their gas supplies and grow more prominent bulges.
Thanks!

Background image: Hickson 44 Galaxy Group (NASA APOD)
Along the MS

- HI, H$_2$ fractions decrease
- SFE, H$_2$/HI \sim constant (t_{DEP} \sim 1.3 \text{ Gyr}, R_{MOL} \sim 0.3)

Flattening of MS at M$_*$/M$_\odot > 10^{10}$ due to gradual decrease of total gas fraction of SF galaxies
Atomic and molecular depletion times

![Plots showing depletion times](image)
Stacking

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