ICRAR

International Centre for Radio Astronomy Research

Star formation and gas supply

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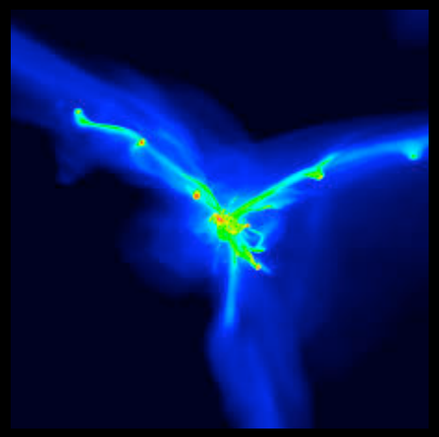
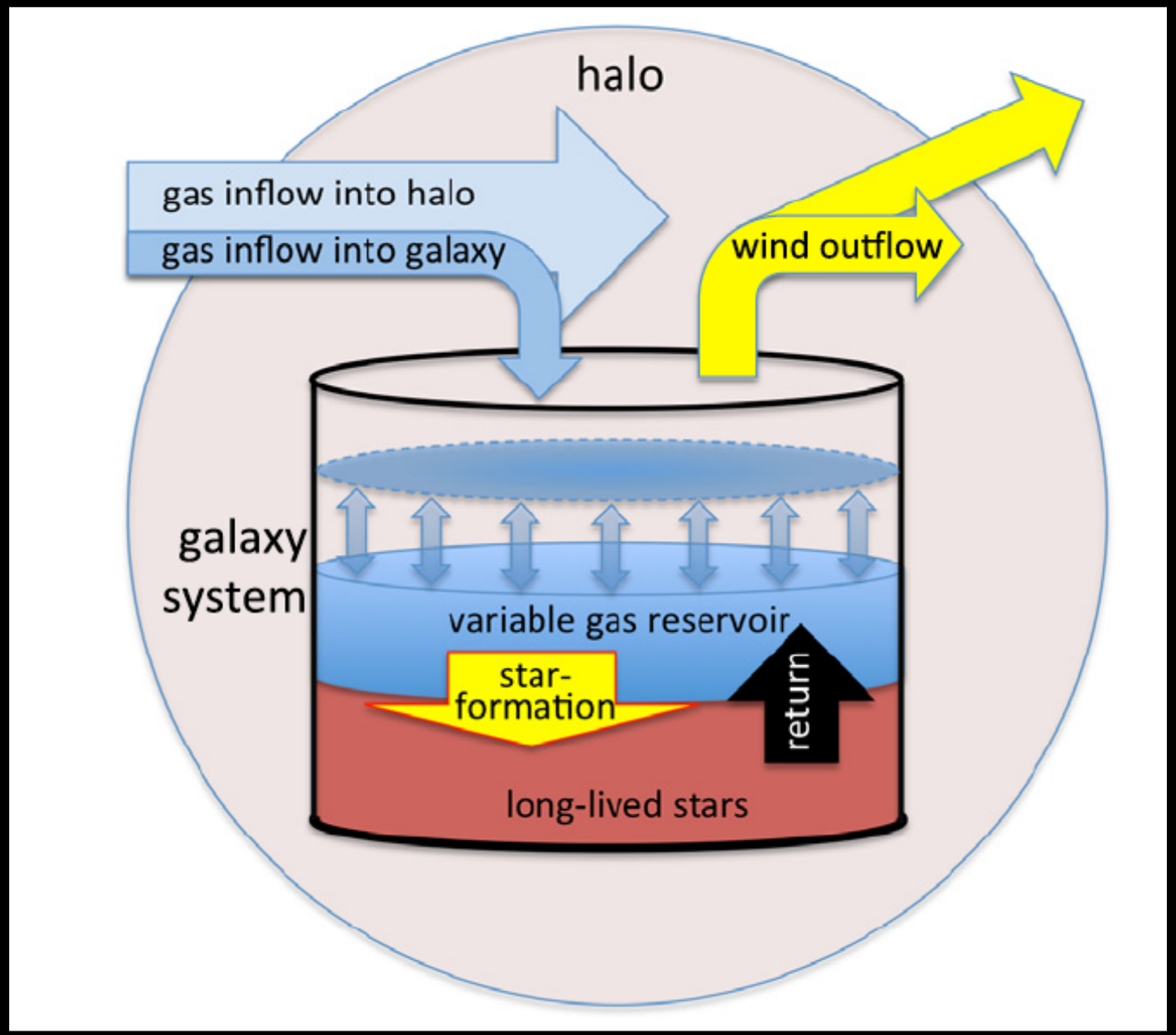
Galaxy evolution in a bathtub



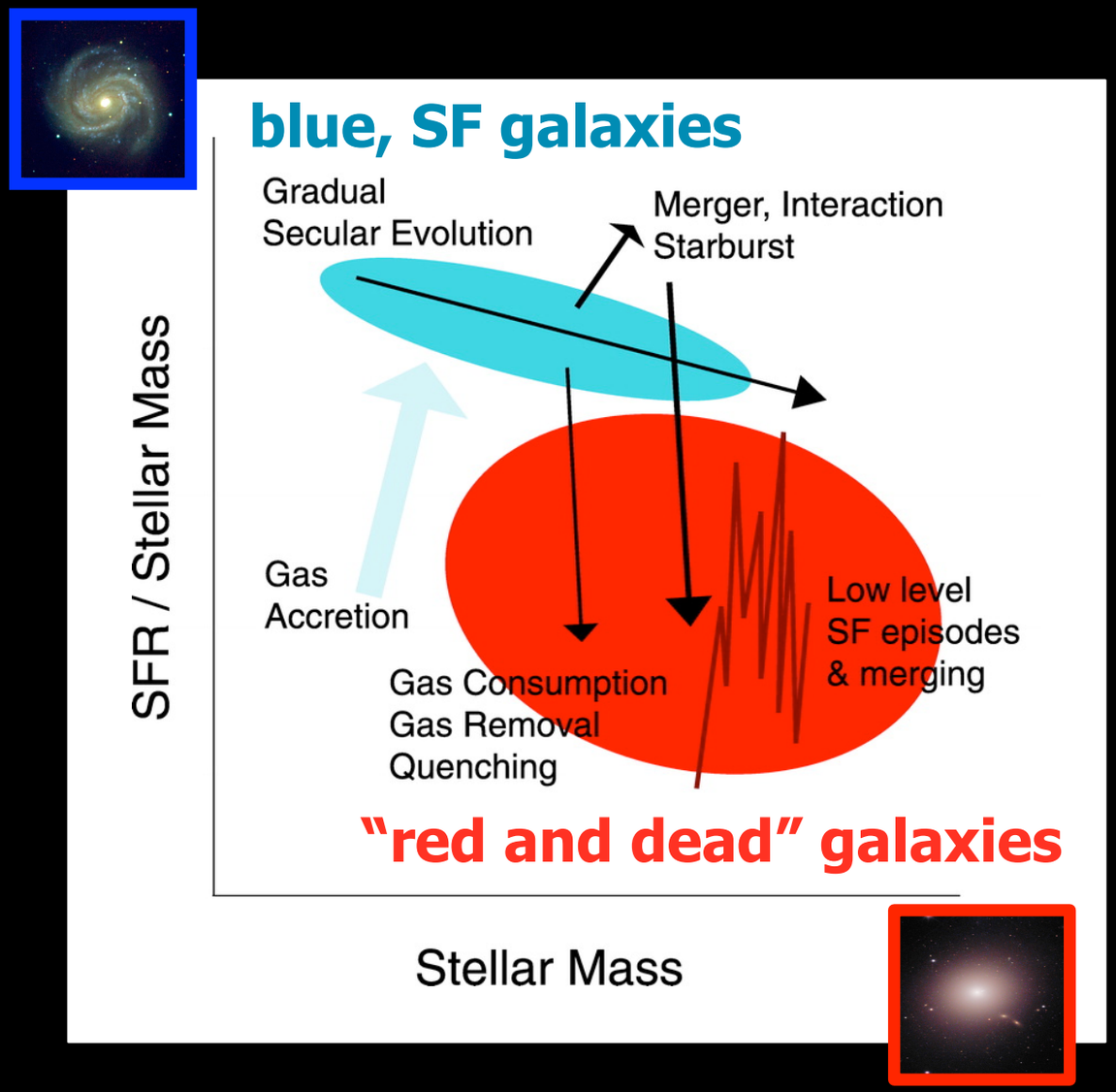


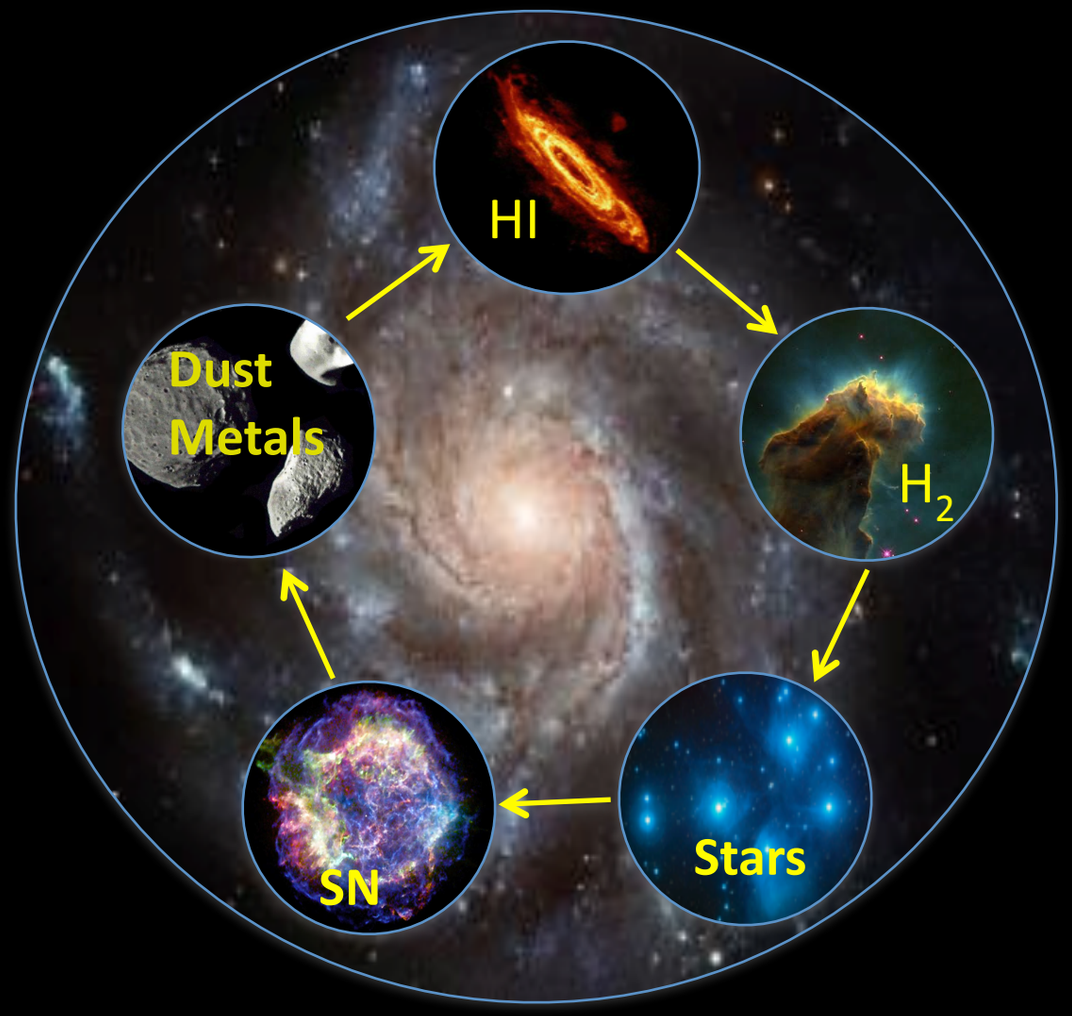
Lilly et al. 2013

see also, e.g. Bouche' et al. (2010), Dave' et al (2011, 2012), Krumholz & Dekel (2012)

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

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:

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

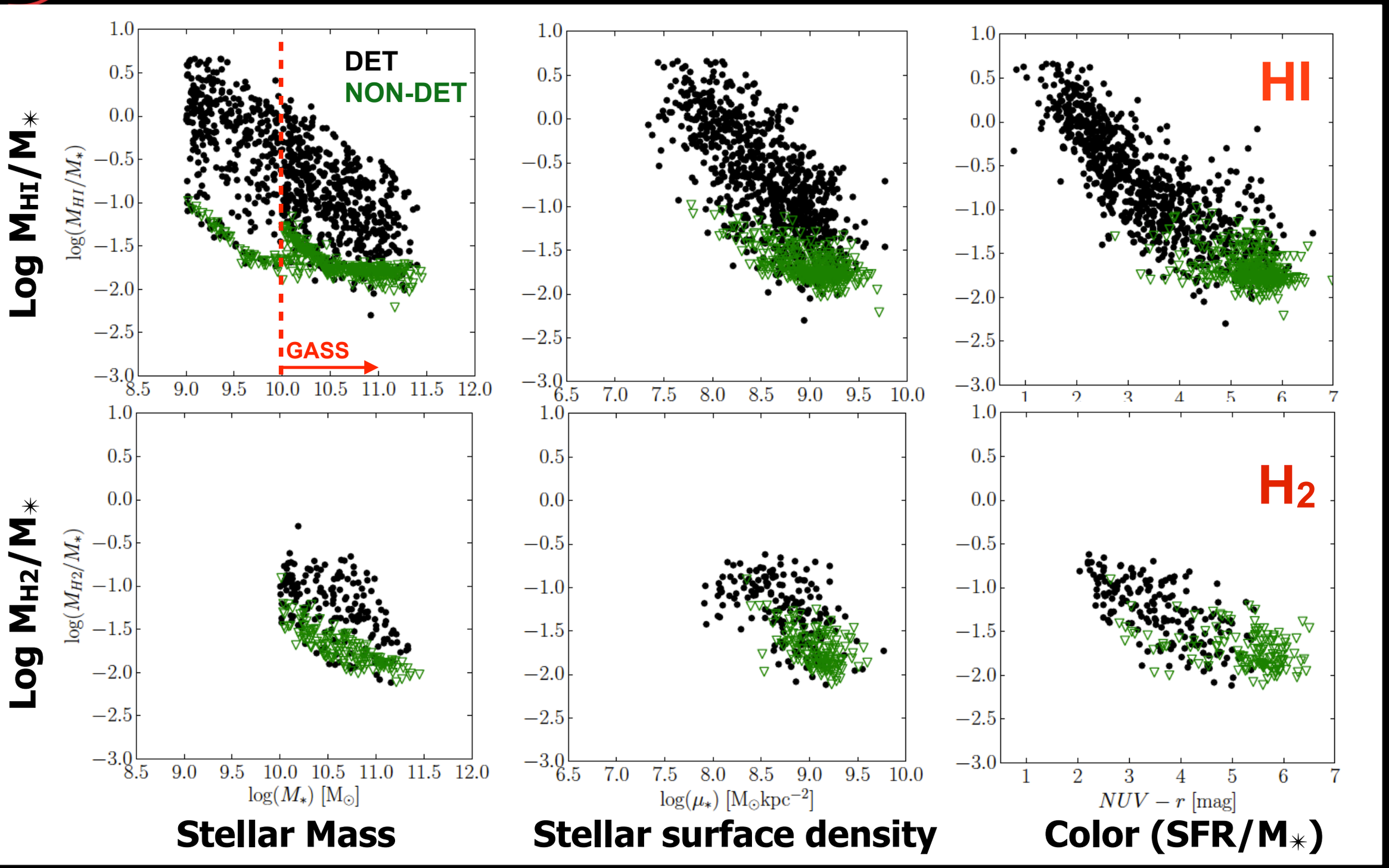
COLD GASS: CO Legacy Database for GASS

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

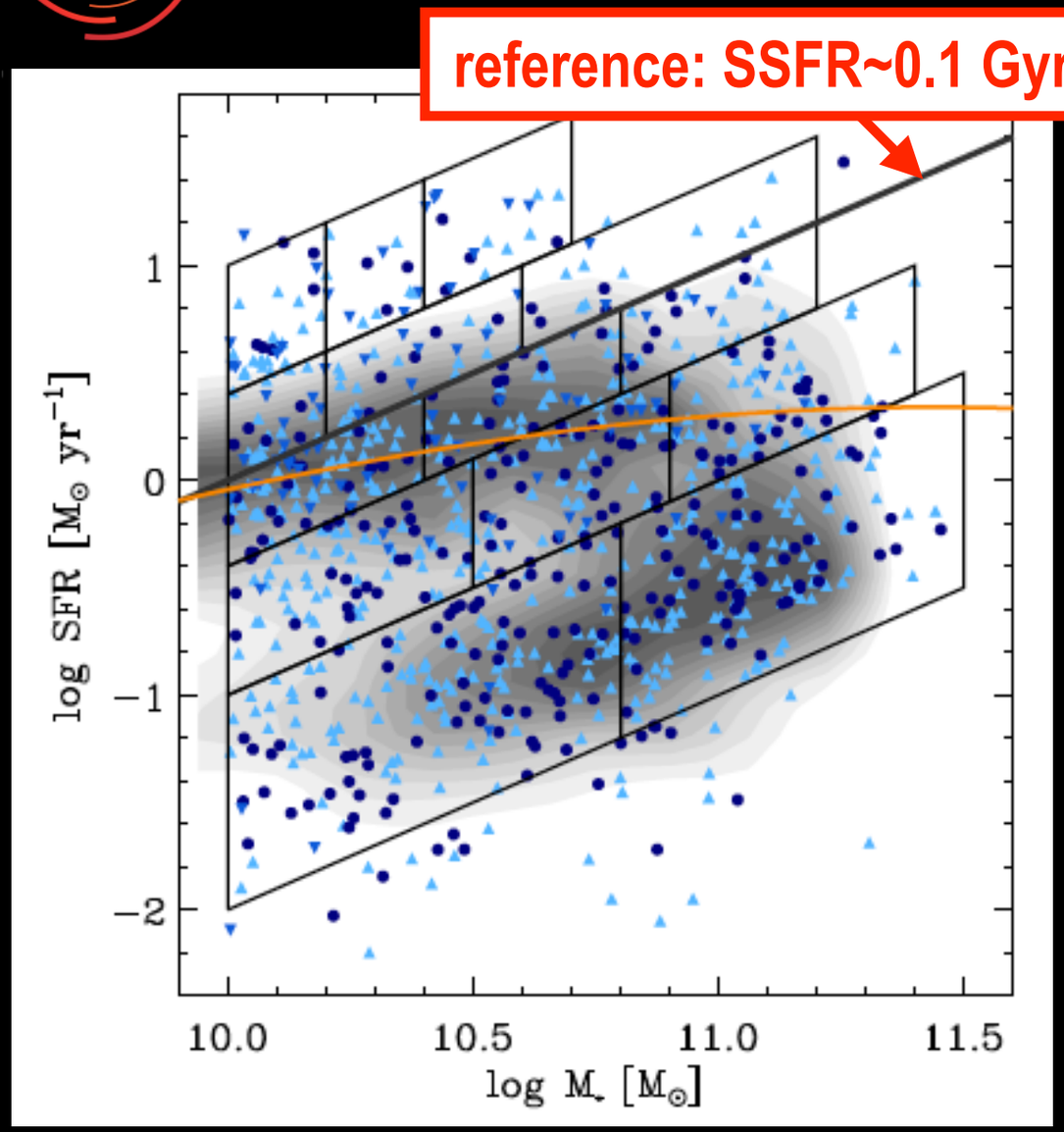
Both surveys now extended to **$\log M_\star/M_\odot = 9$**

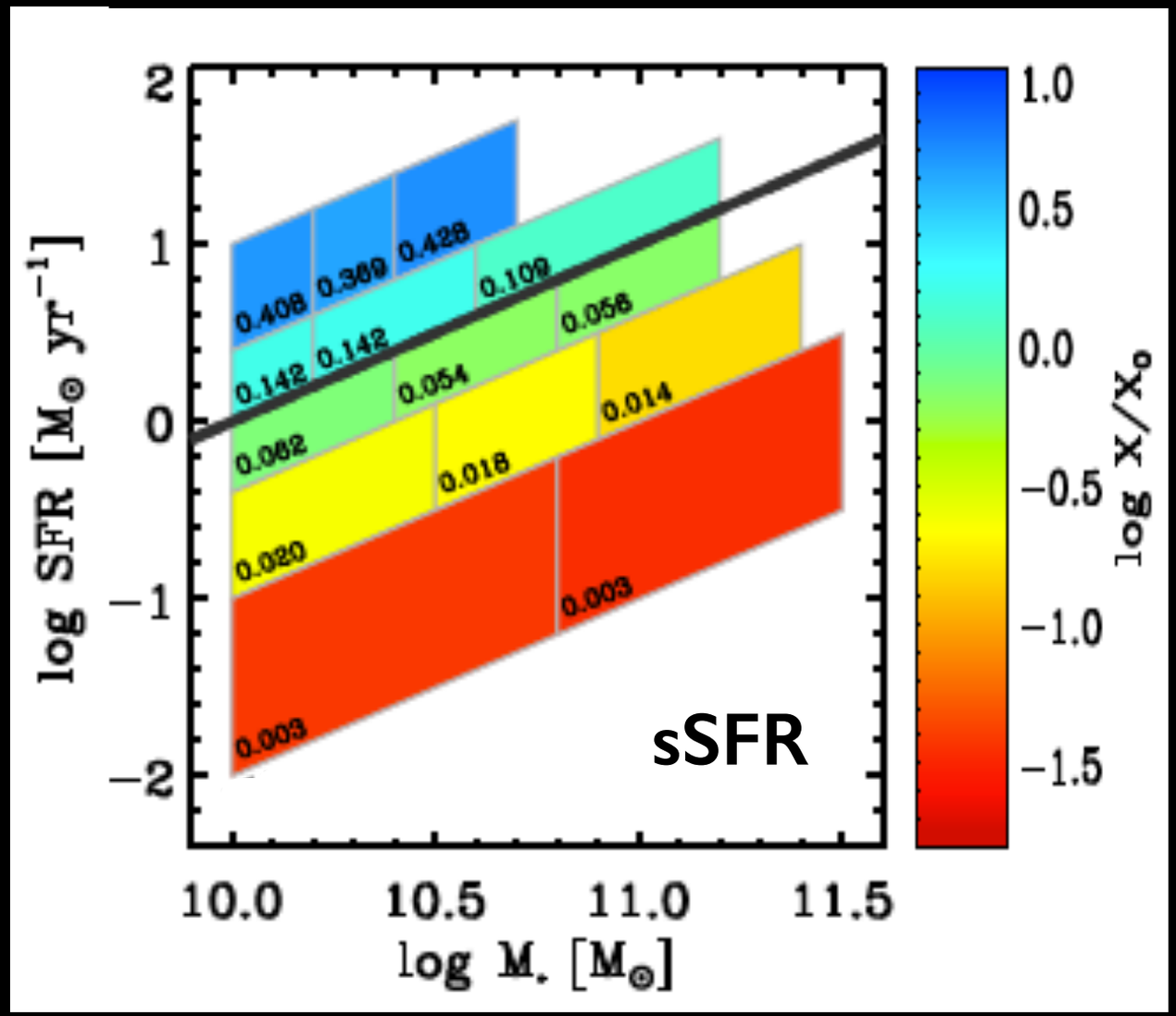
Gas scaling relations



Catinella et al. 2013 + in prep., Saintonge et al. 2011

Dissecting the SFR-stellar mass plane



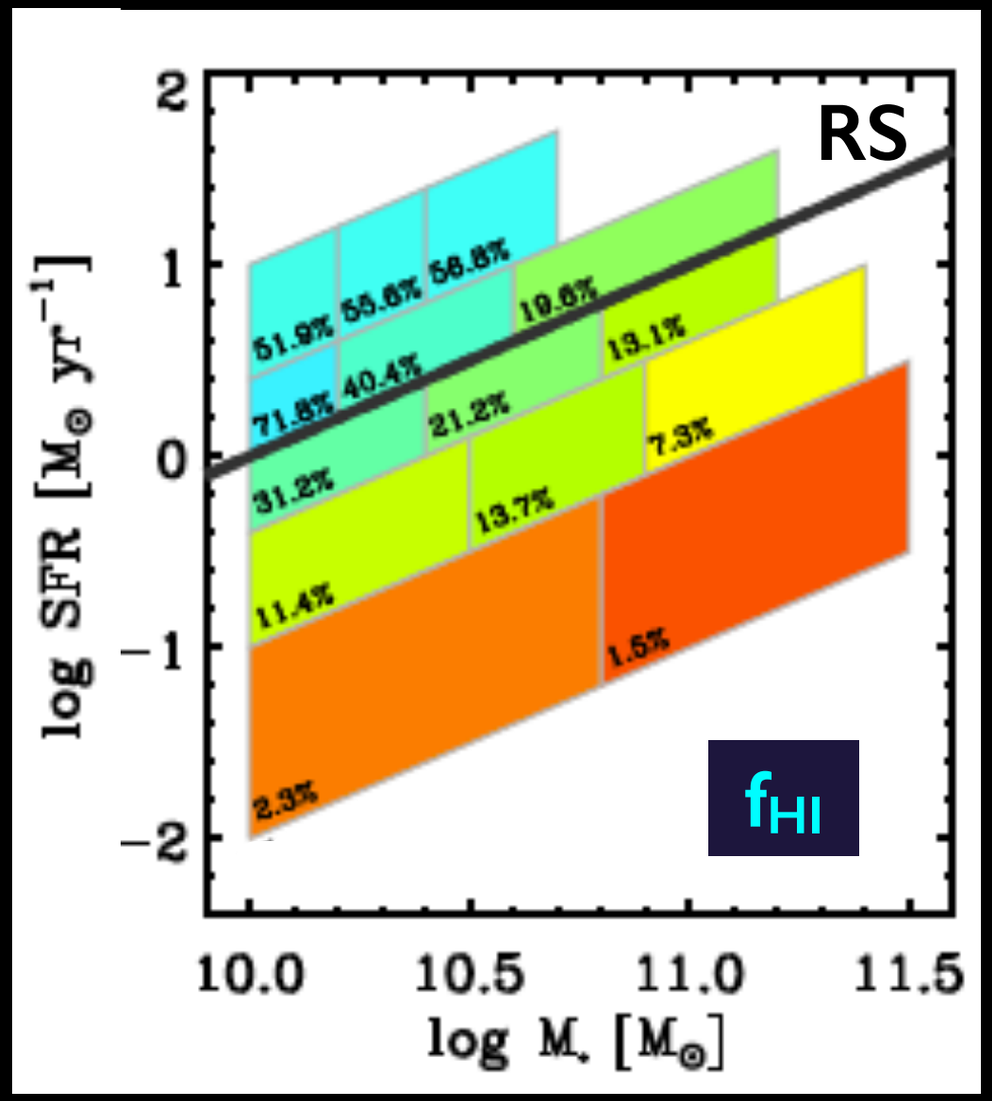


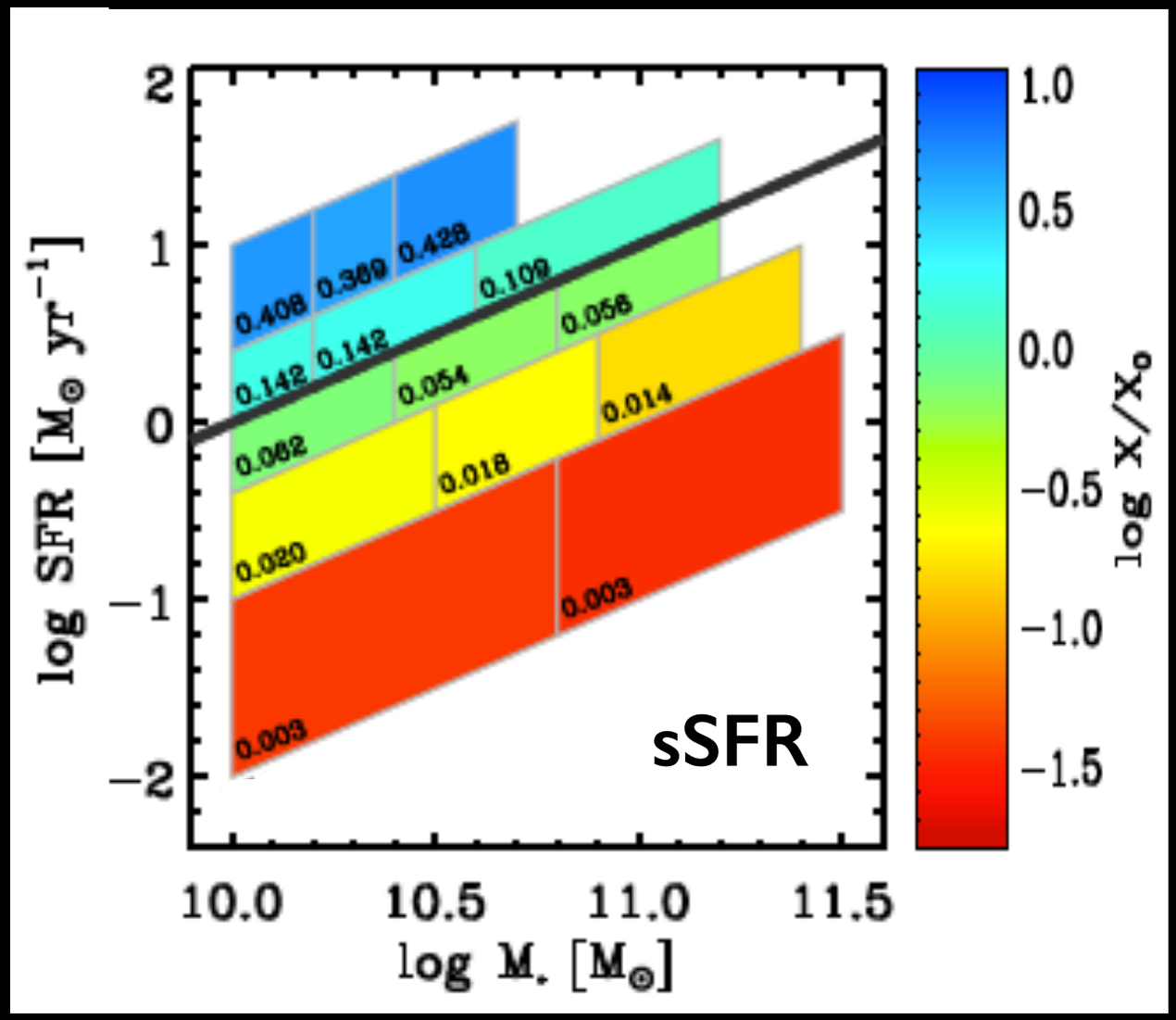
Saintonge, Catinella et al. subm.

$$\mathbf{sSFR} = \frac{SFR}{M_\star} = \frac{M_{HI}}{M_\star}\,\frac{M_{H2}}{M_{HI}}\,\frac{SFR}{M_{H2}} = f_{HI}\;R_{mol}\;SFE_{H2}$$

f_{HI} → feeding; R_{mol} → fueling; SFE_{H2} → consuming

Atomic hydrogen

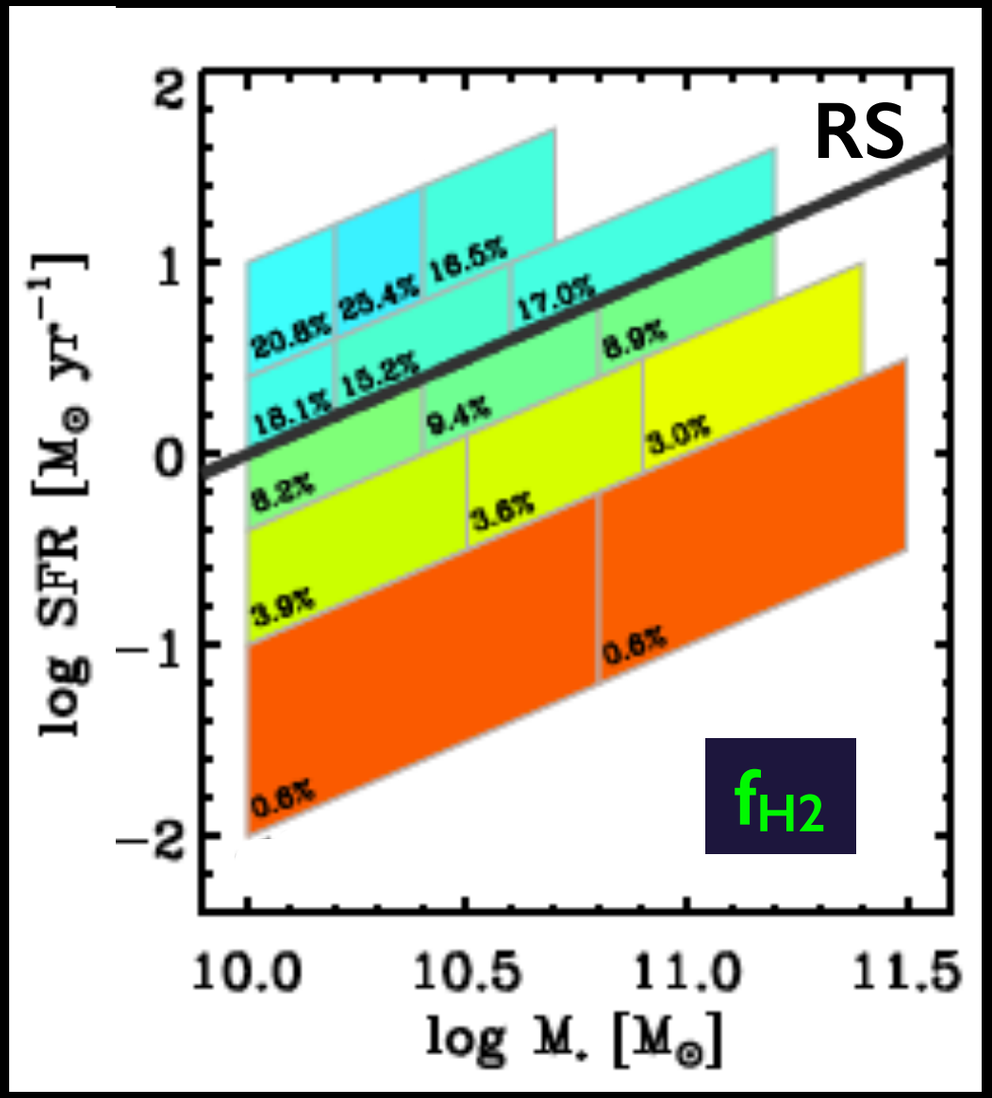


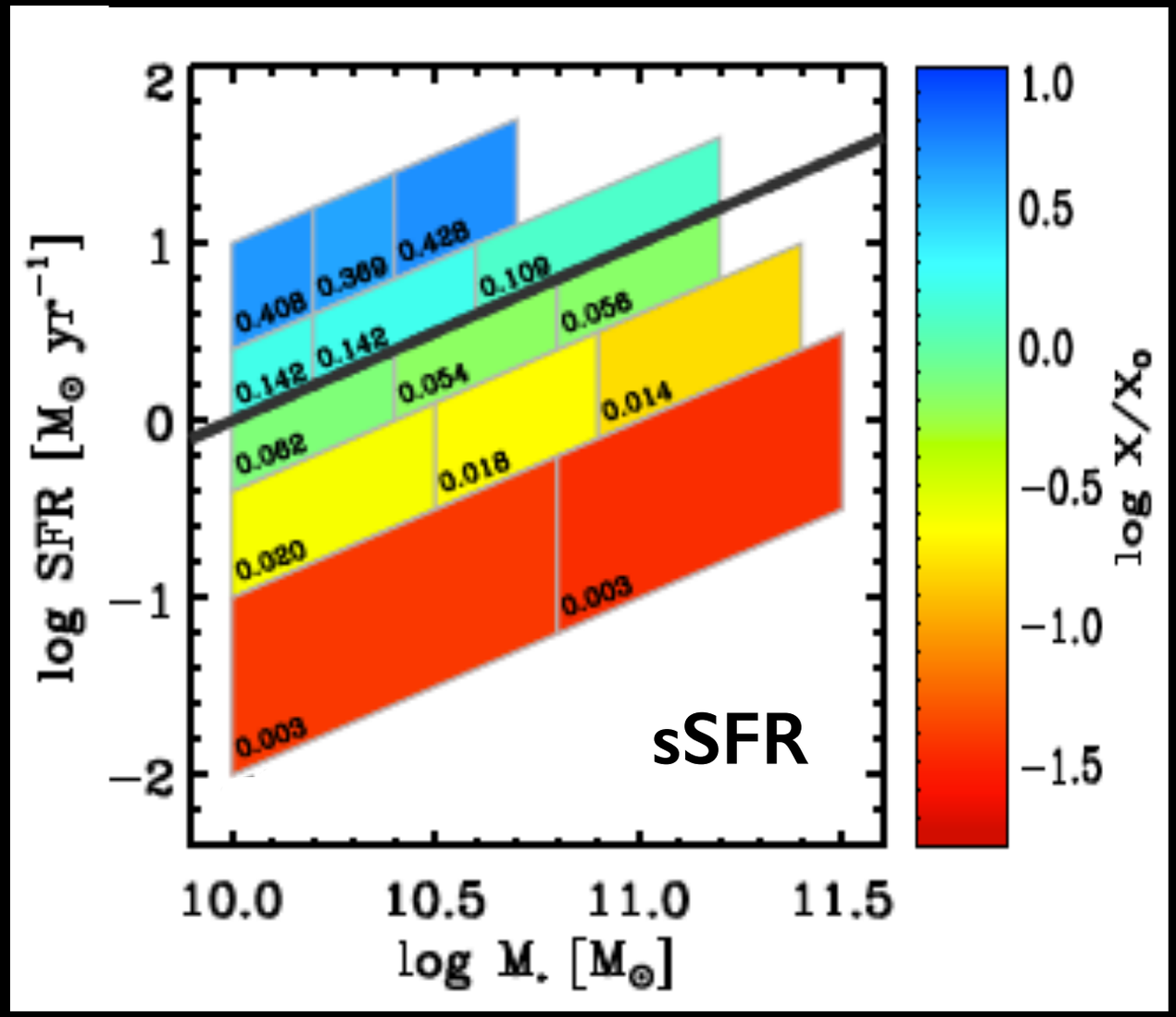


Saintonge, Catinella et al. subm.

- HI content varies mostly **across**, but also **along** reference sequence (RS)
- HI alone cannot explain variation of sSFR (lack of dyn range)

Molecular hydrogen



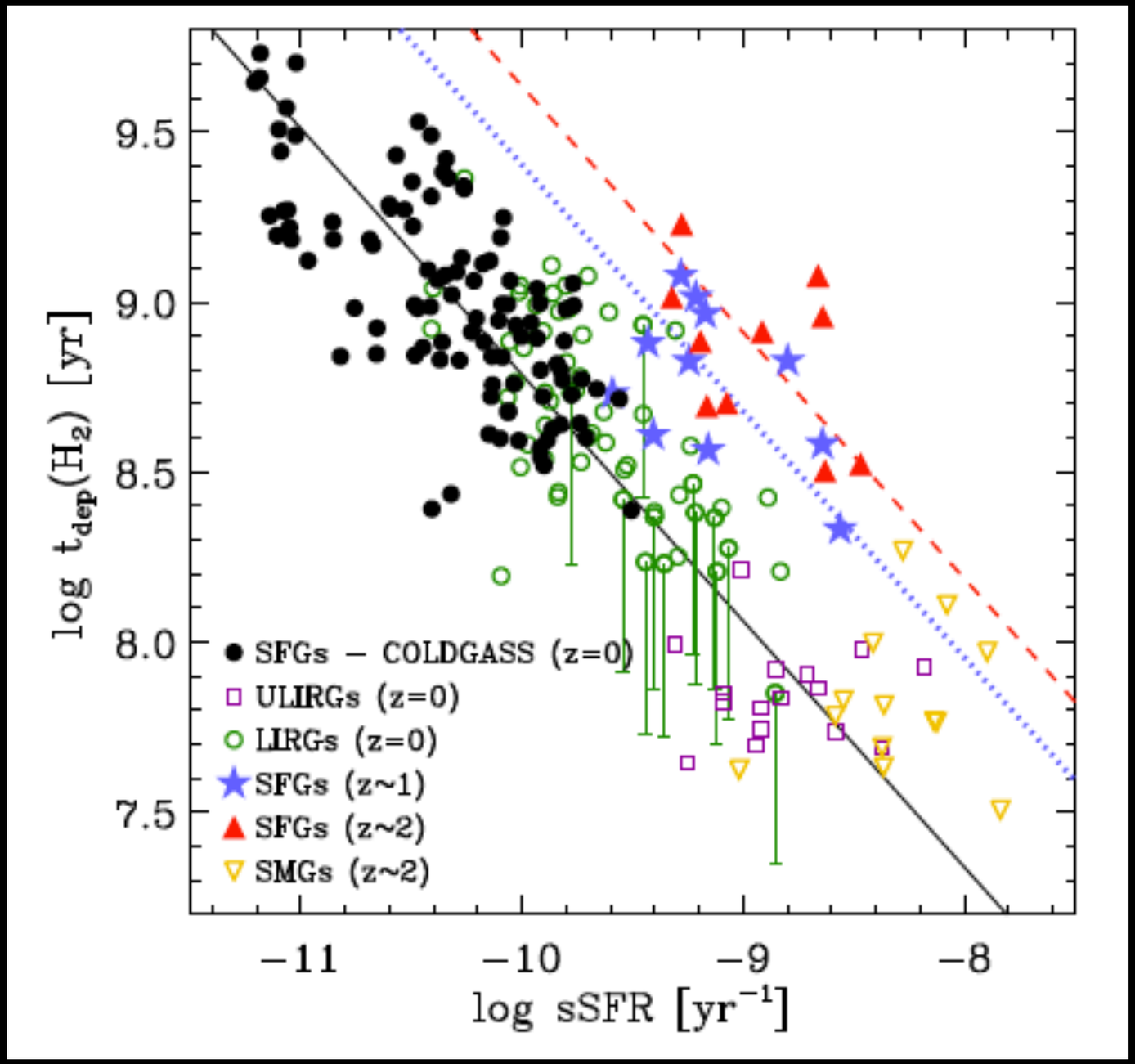


Saintonge, Catinella et al. subm.

$$f_{H2} = \frac{M_{HI}}{M_\star} \frac{M_{H2}}{M_{HI}} = f_{HI}\ R_{mol}$$

- H_2 content varies almost only **across** RS
- H_2 alone cannot explain variation of sSFR

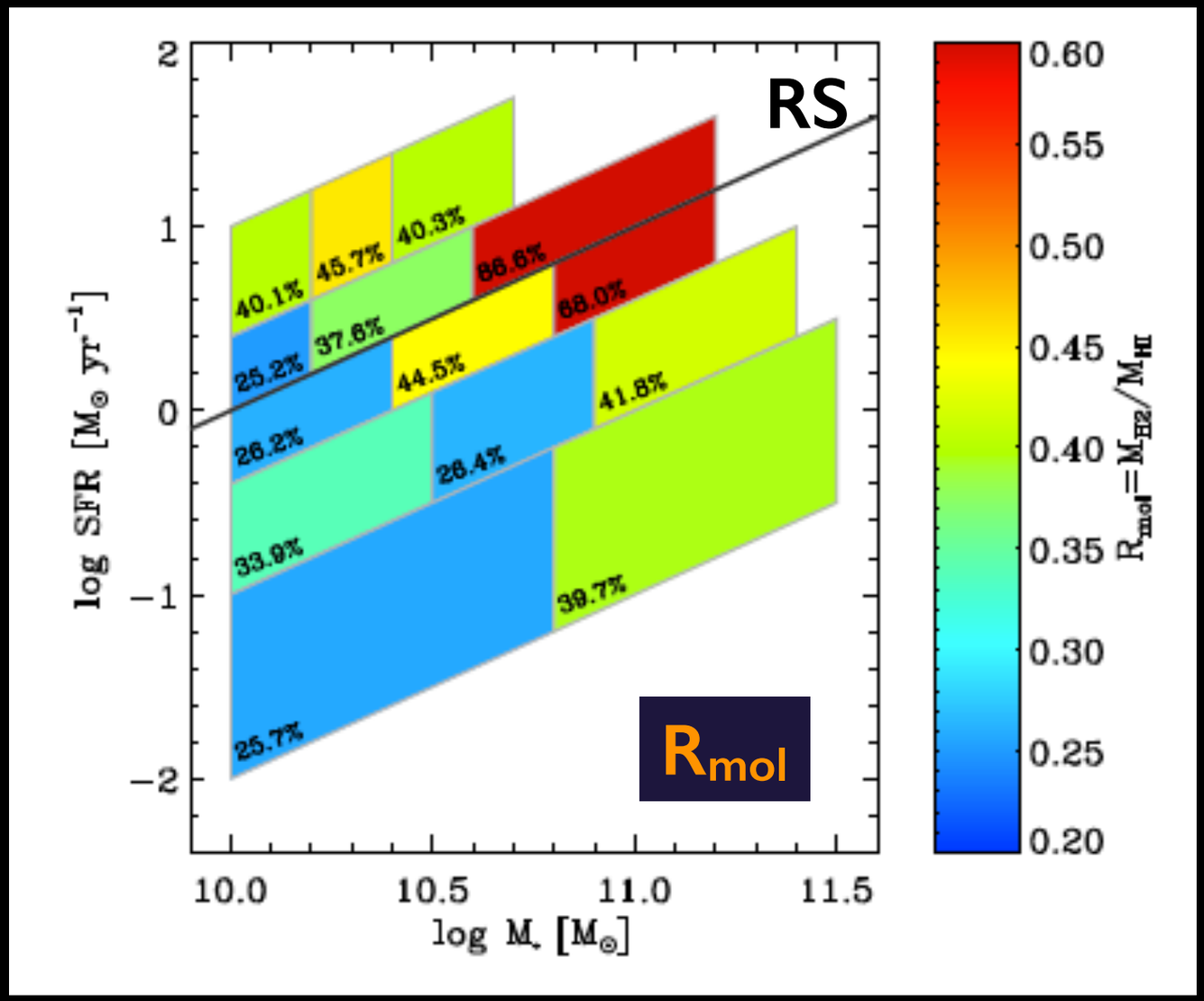
SFE is not constant



Saintonge et al. 2011

$t_{DEP} = M_{H2} / SFR = 1 / SFE$

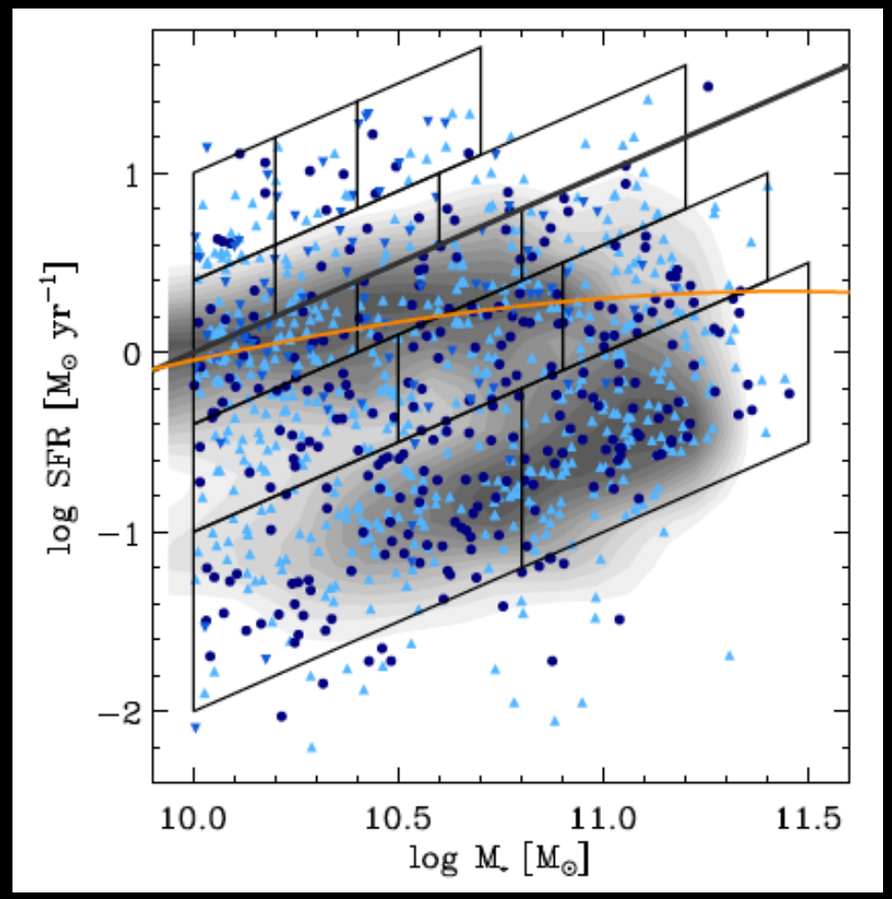
Molecular-to-atomic hydrogen ratio



Saintonge, Catinella et al. subm.

H_2/HI content varies **along** RS (on the RS, from 25% to >70%!!)

Cold gas in the SFR-stellar mass plane



Saintonge, Catinella et al. subm.

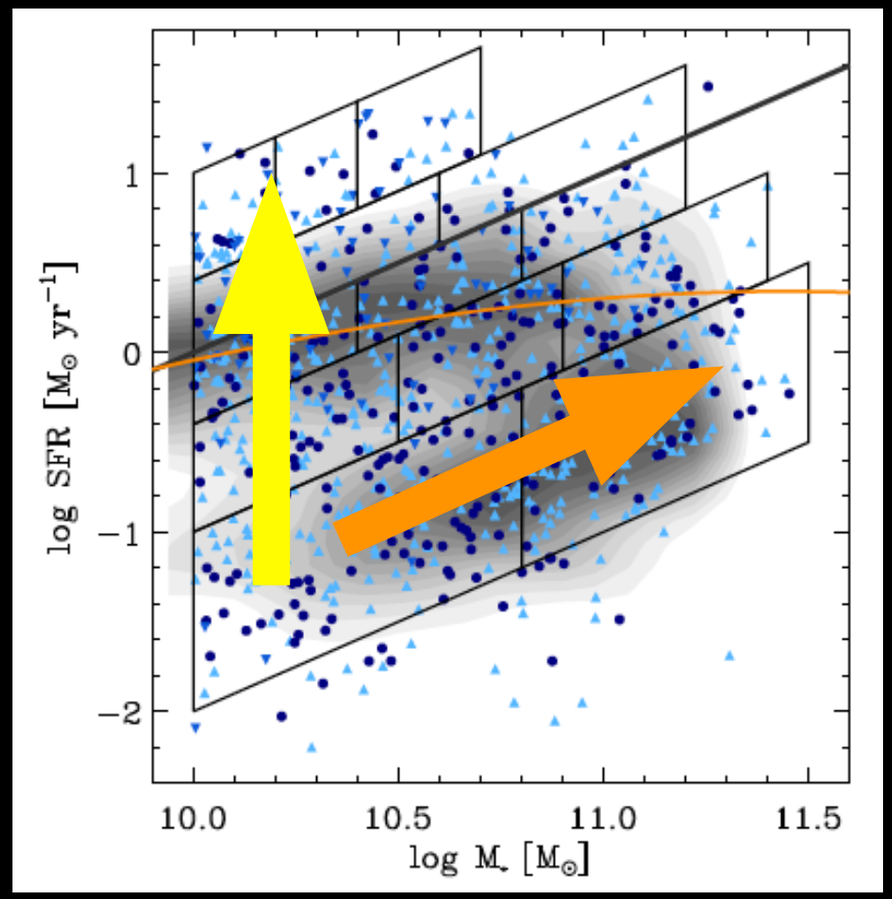
$$\text{sSFR} = \frac{\text{SFR}}{M_\star} = f_{HI}\ R_{mol}\ SFE_{H2}$$

feeding fueling consuming

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

Cold gas in the SFR-stellar mass plane



Saintonge, Catinella et al. subm.

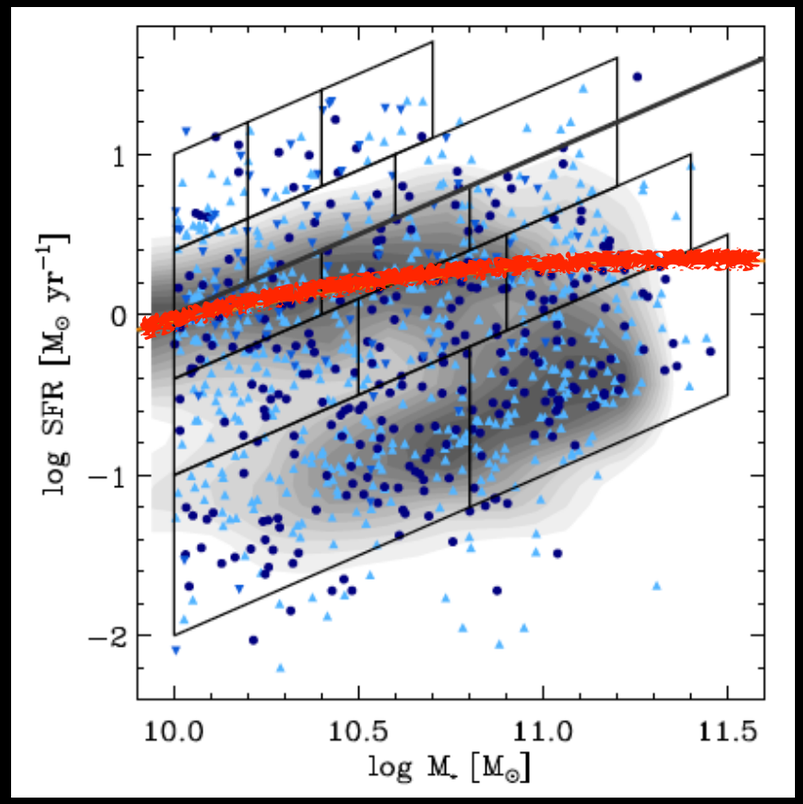
$$sSFR = \frac{SFR}{M_\star} = f_{H2} \; f_{HI} \; R_{mol} \; SFE_{H2}$$

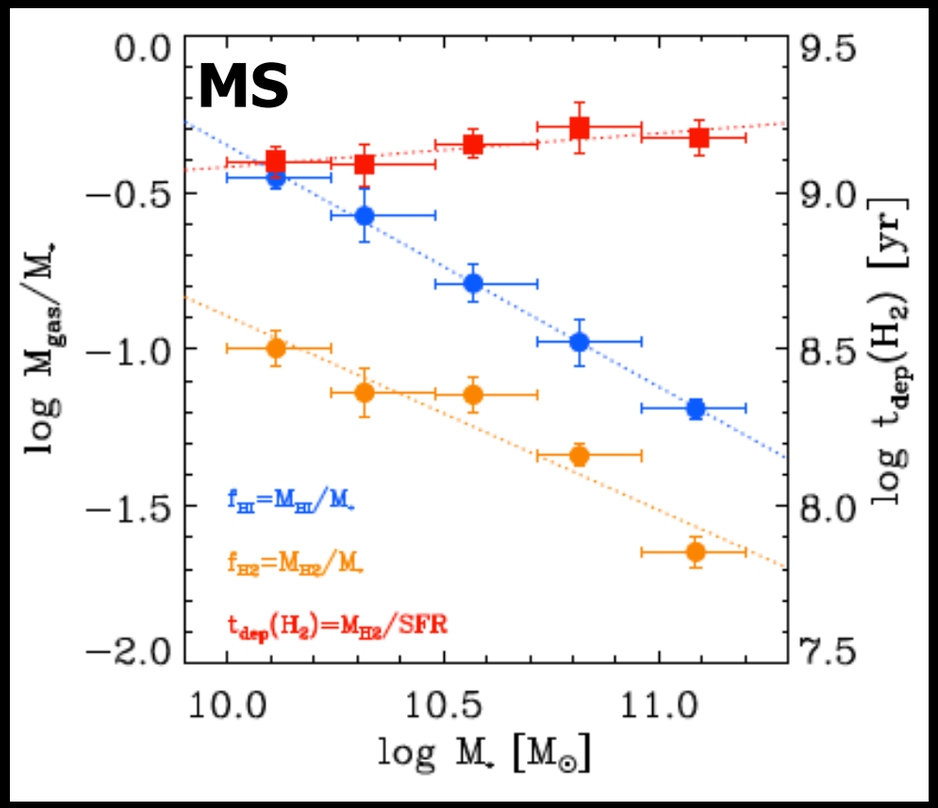
feeding fueling consuming

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

Main sequence of SF galaxies





Saintonge, Catinella et al. subm.

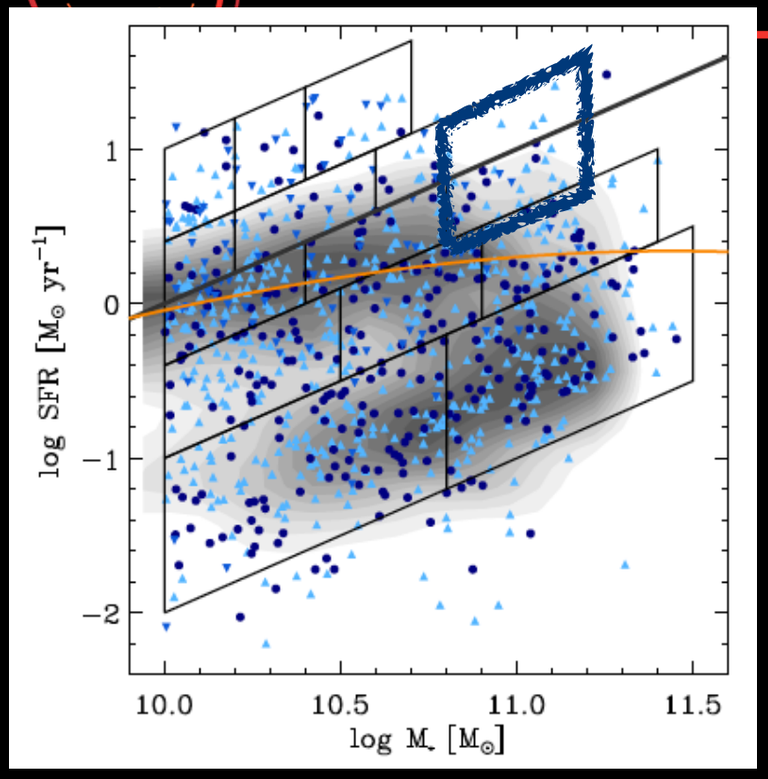
Along the MS

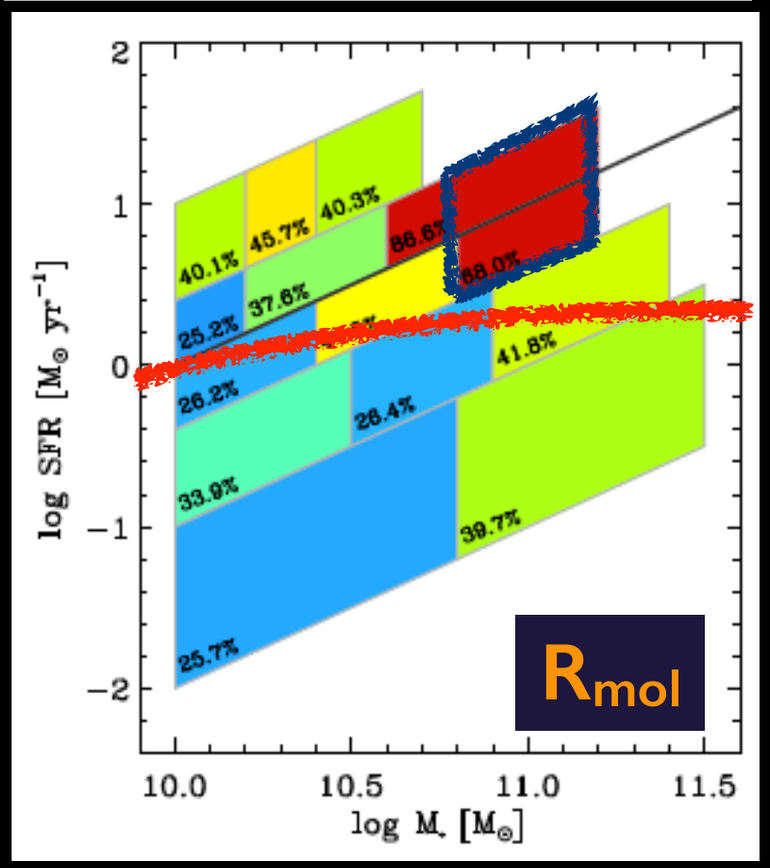
- HI, H_2 fractions decrease
- SFE, H_2/HI ~ constant (t_{DEP}~ 1.3 Gyr, R_{MOL}~0.3)

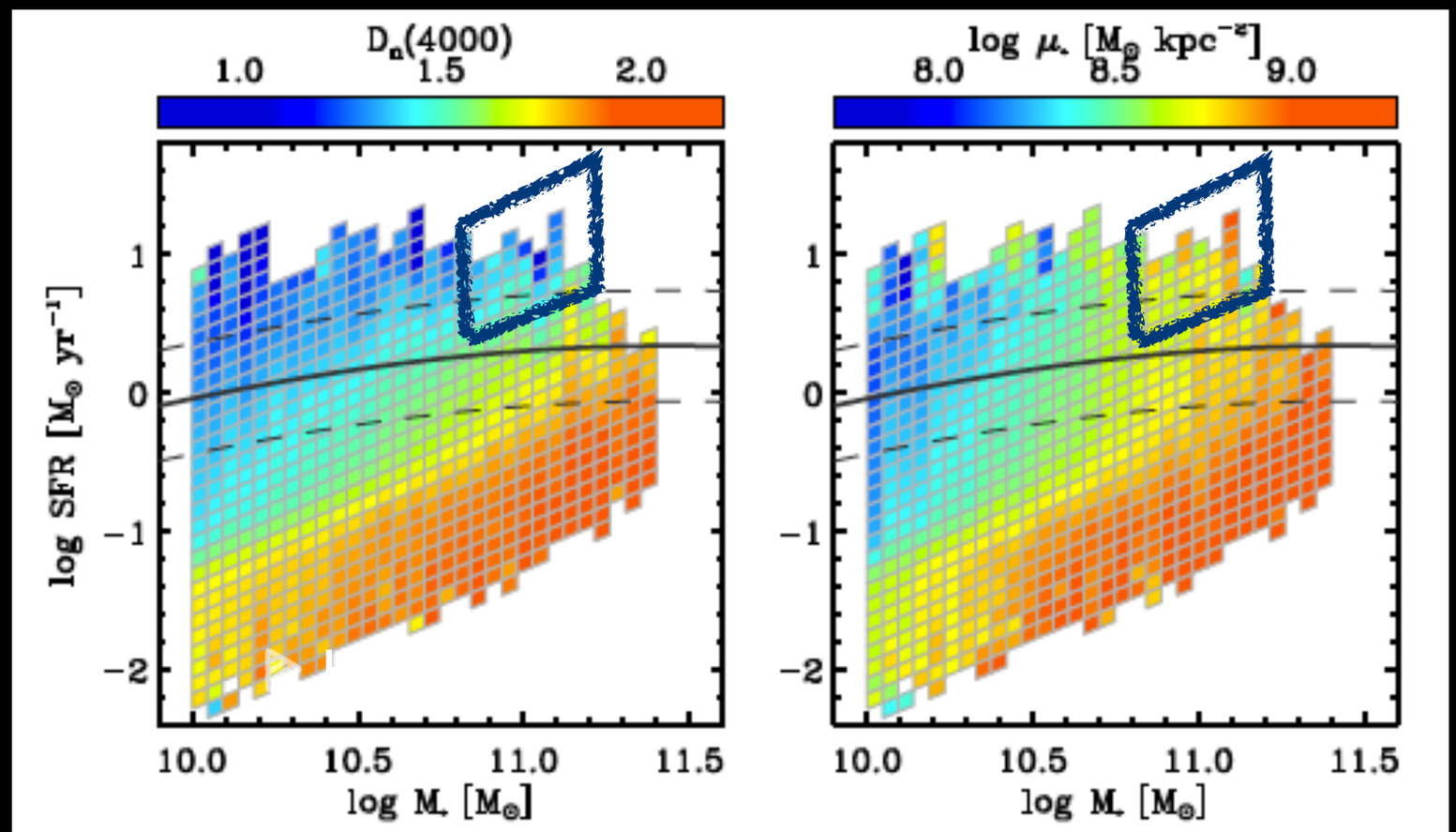
$$sSFR = f_{HI}\ R_{mol}\ SFE_{H2}$$

Flattening of MS at $M_\star/M_\odot > 10^{10}$ due to gradual decrease of total gas fraction of SF galaxies

Quenching “danger zone”





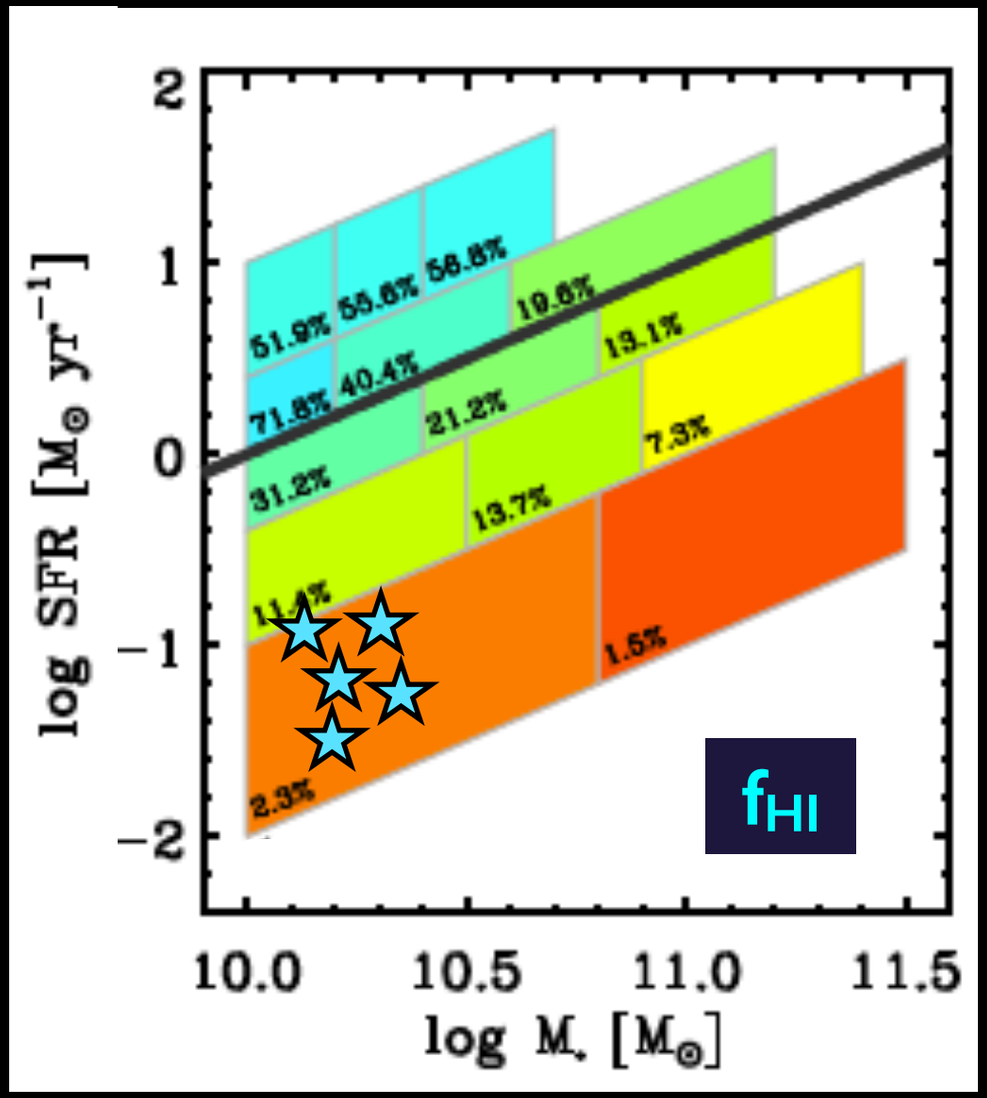


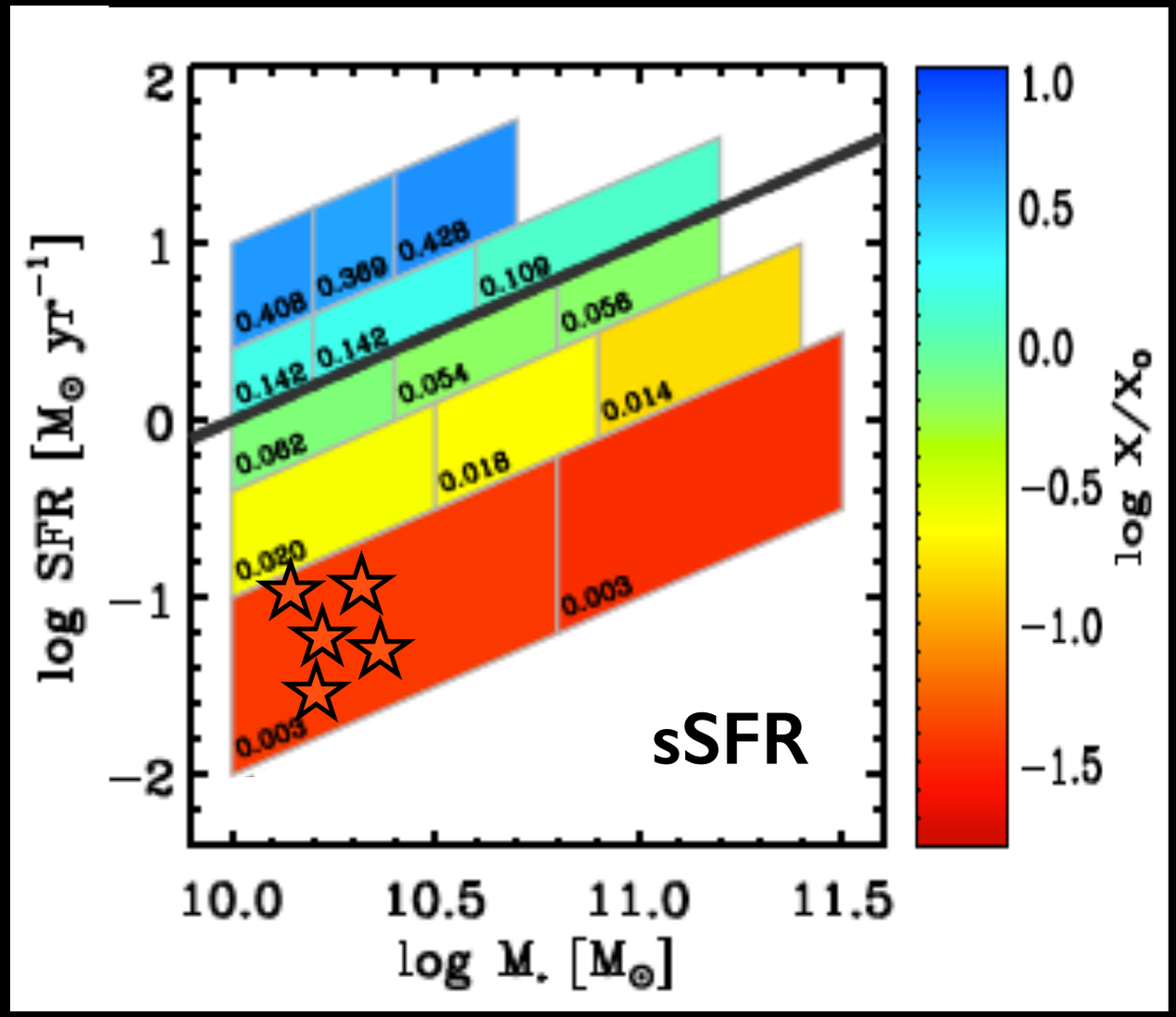
Saintonge, Catinella et al. subm.

Very high H_2/HI >70%, total gas mass ~10^{10} $M_\odot$,
SFR~ 10 $M_\odot$/yr —> **w/in ~1 Gyr of quenching!**

Unusual combination of bulge+young stellar populations in the central regions

An indirect look into the scatter

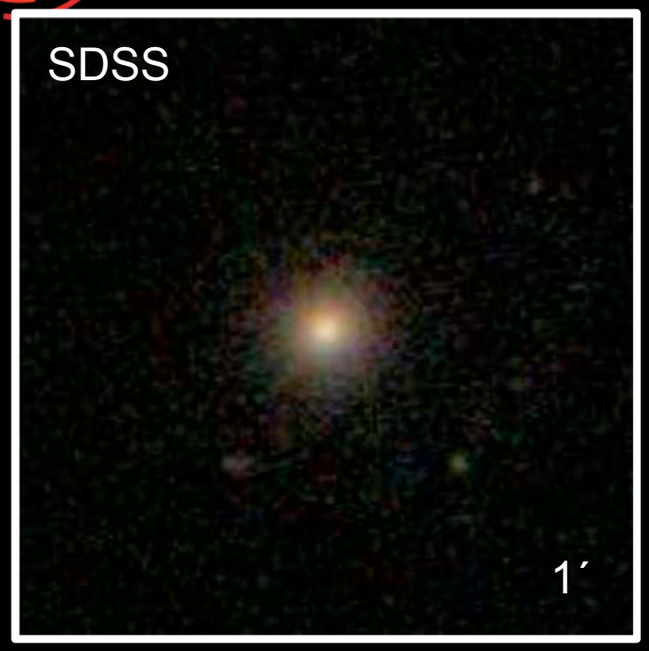


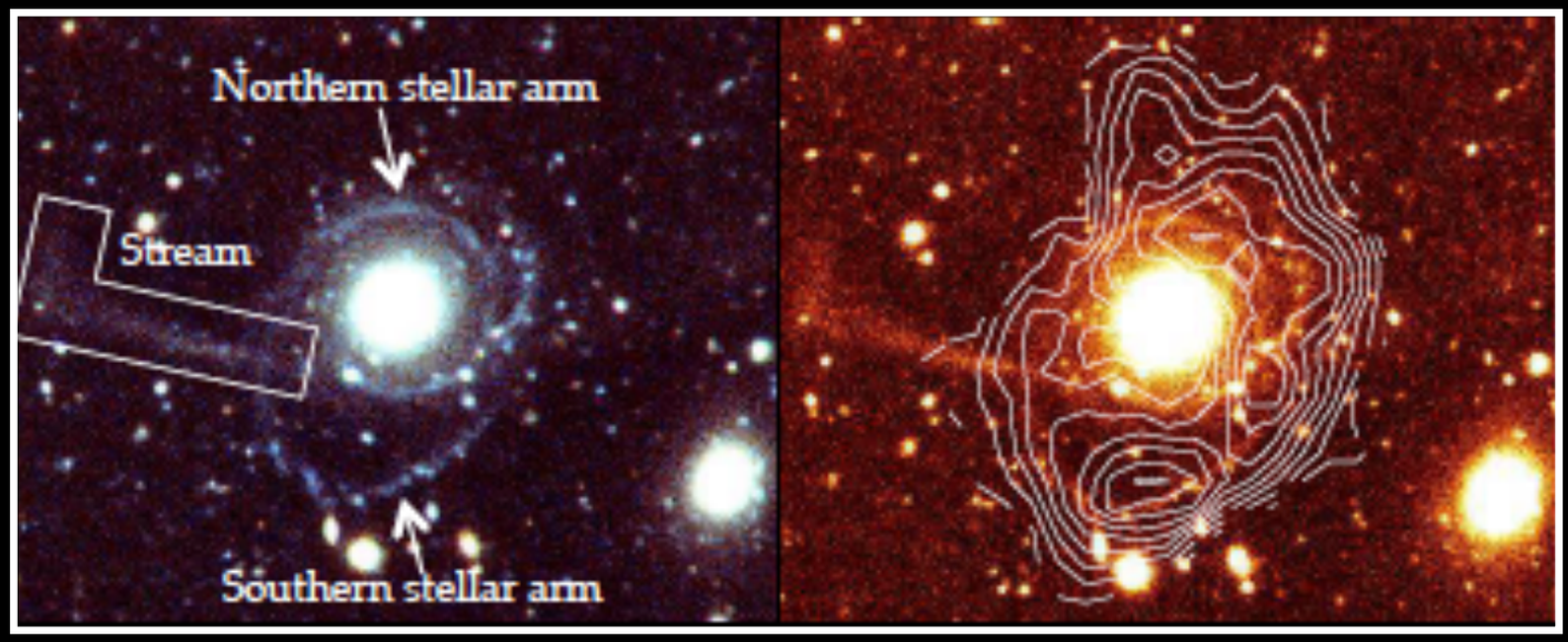


Saintonge, Catinella et al. subm.

HI excess galaxies: interesting population of galaxies with huge HI reservoirs that are not forming stars ➔ outliers of f_{HI} vs sSFR relation

GASS 3505: the HI excess prototype





Geréb, Catinella et al. (subm.)

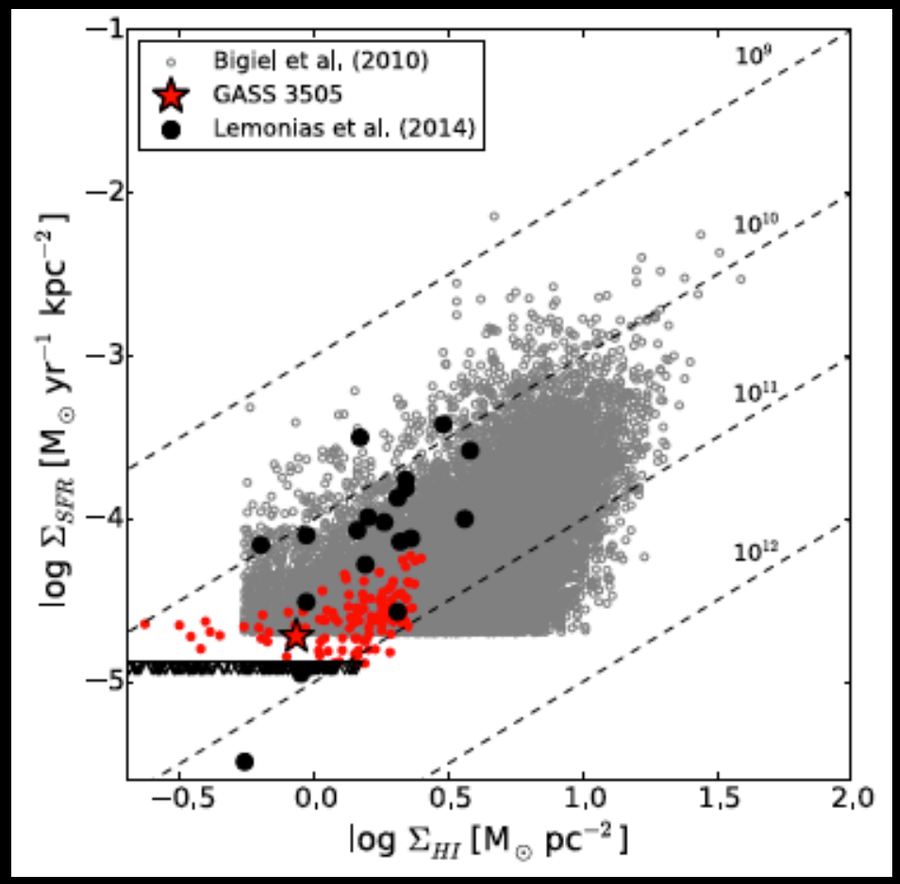
HI mass ~10^{10} $M_\odot$!!

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

M_{H2} / $M_\star$ < 0.05

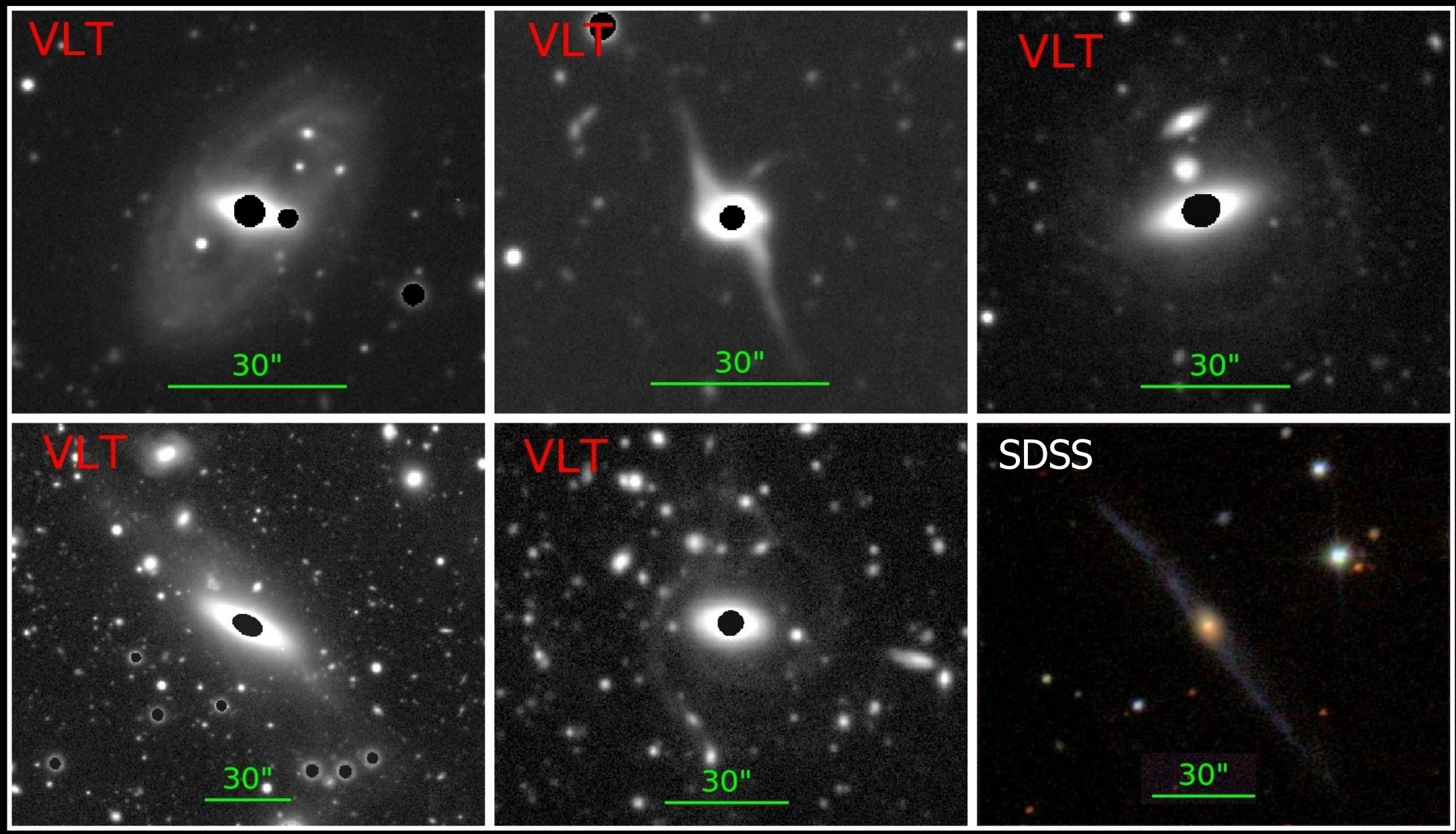
SFR= 0.1 $M_\odot$/yr

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



HI excess population

HI excess population



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

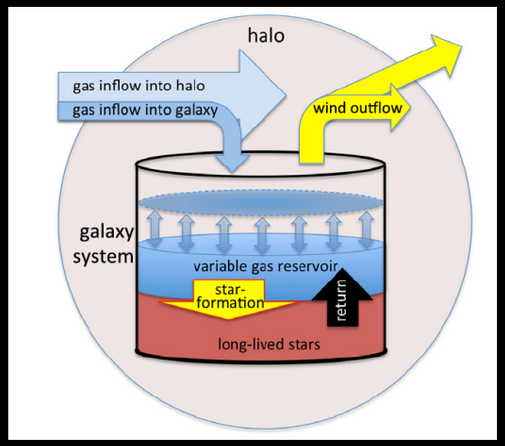
Summary

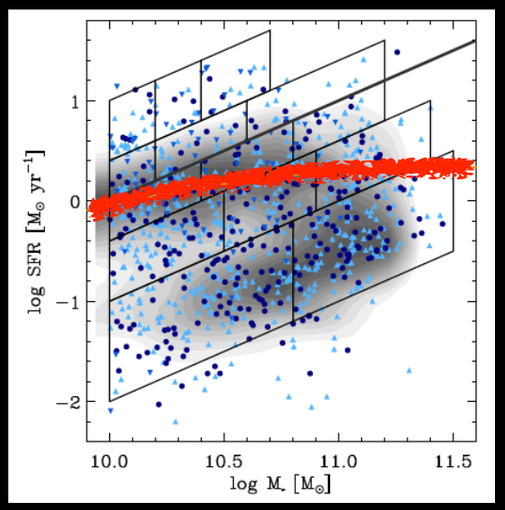
- Large, unbiased samples of galaxies with **atomic and molecular gas** measurements are key to understand galaxy evolution

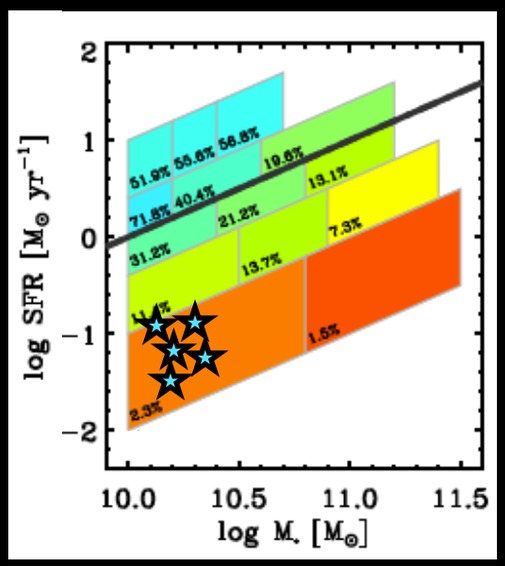
- Position of galaxy in the SFR-M⋆ plane depends on
  1. Amount of gas
  2. How much of it is available for SF
  3. Efficiency of the conversion of this gas into stars

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

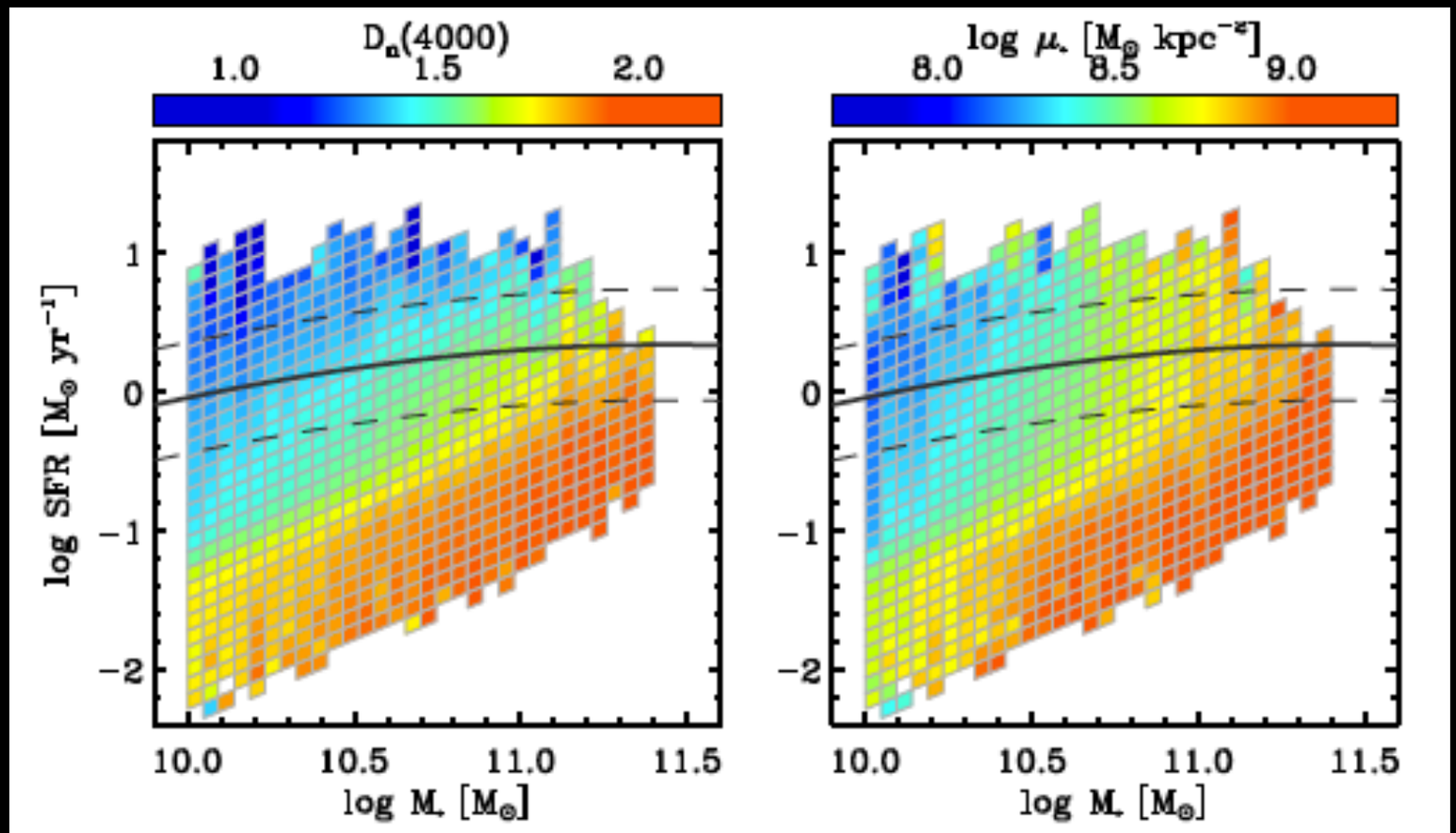
- Interesting populations of galaxies about to run out of gas, or with huge gas reservoirs that are not forming stars

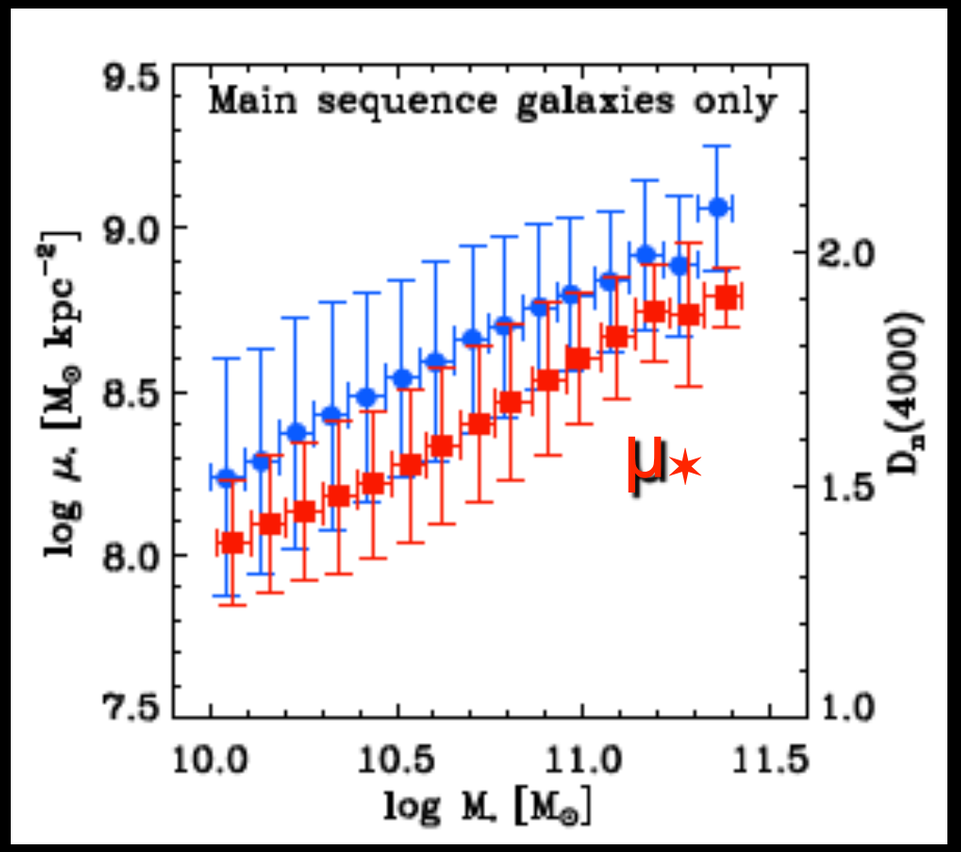






Main sequence of SF galaxies and morphology





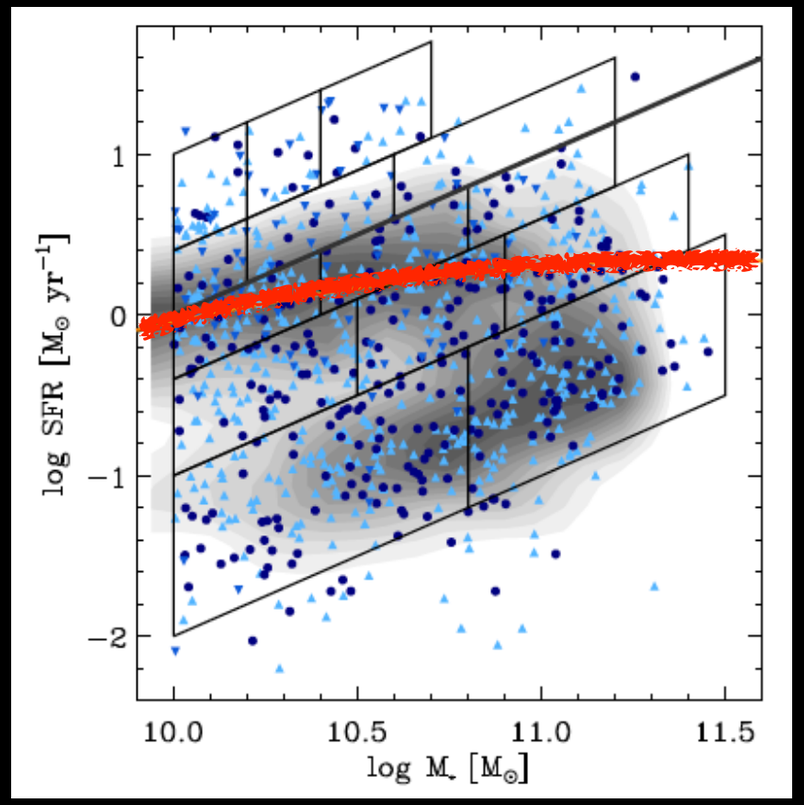
Saintonge, Catinella et al. subm.

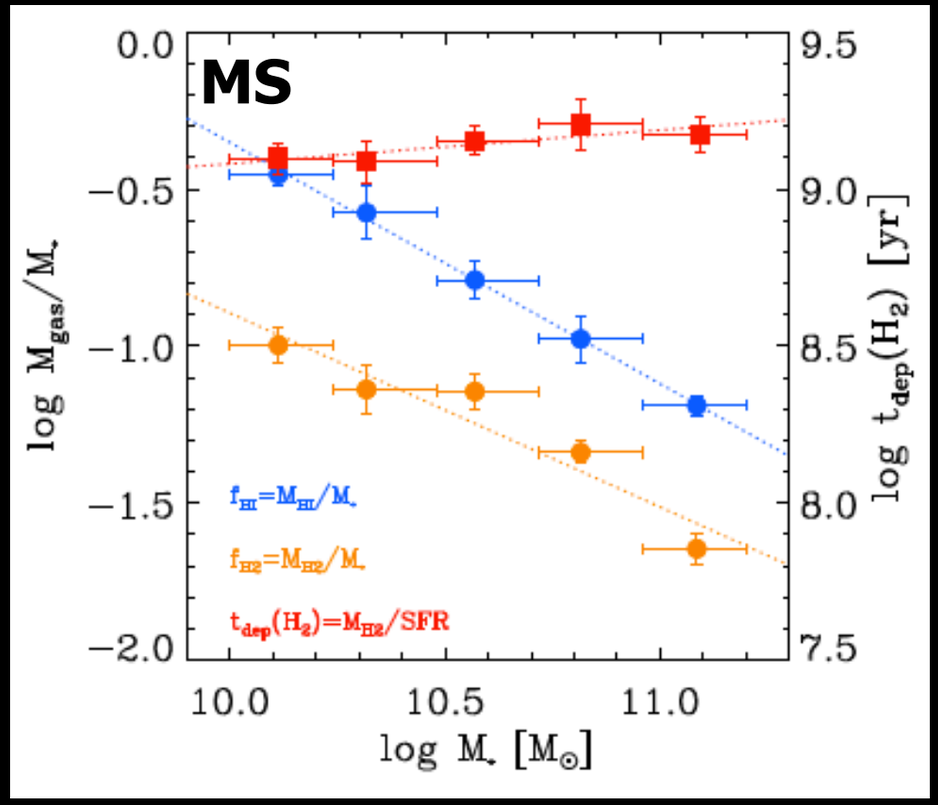
On the MS, as mass increases galaxies steadily consume their gas supplies **and grow more prominent bulges**

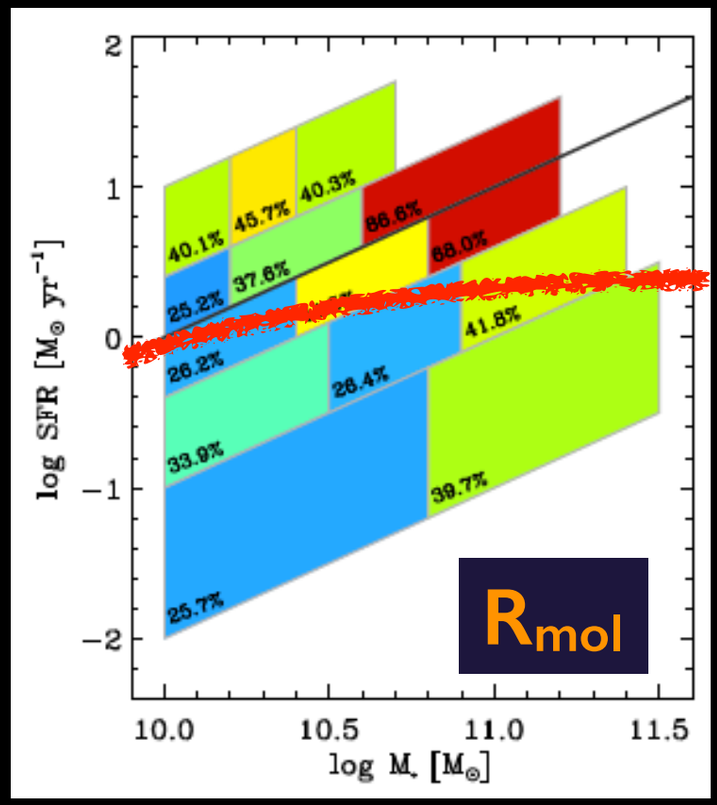
Thanks!

Background image: Hickson 44 Galaxy Group (NASA APOD)

Main sequence of SF galaxies







Saintonge, Catinella et al. subm.

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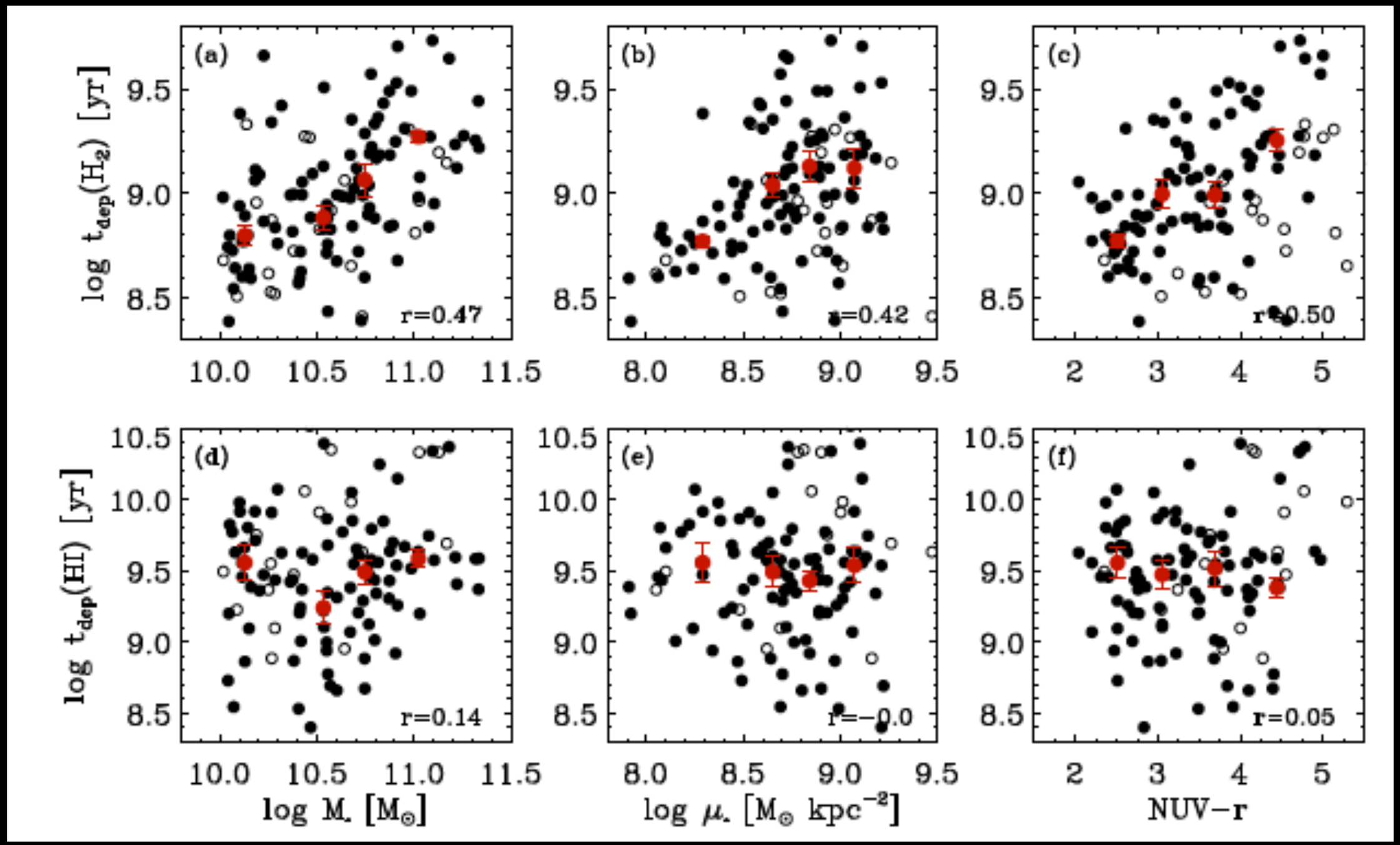
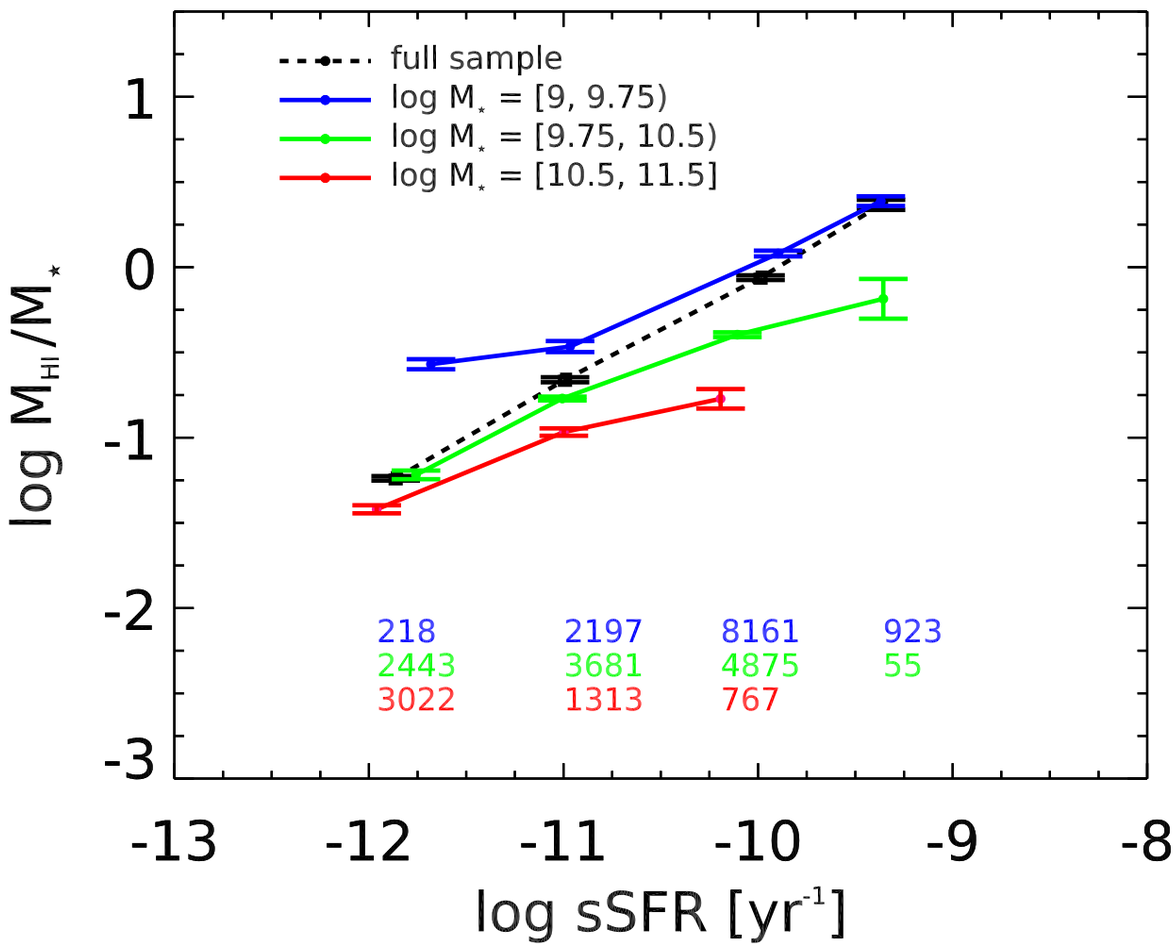
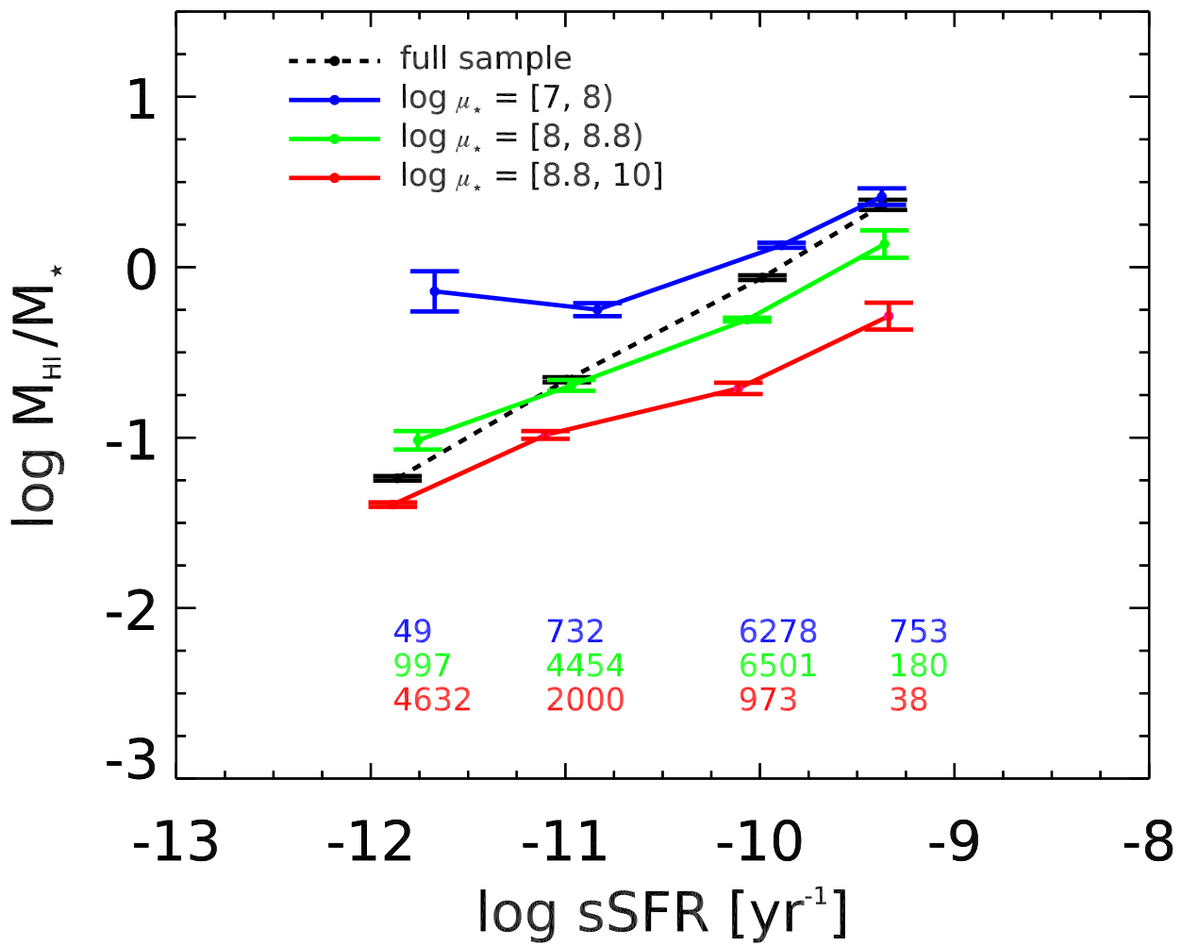
Flattening of MS at $M_\star/M_\odot > 10^{10}$ due to gradual decrease of total gas fraction of SF galaxies

Atomic and molecular depletion times



Stacking


full sample
log M⋆ = [9, 9.75)
log M⋆ = [9.75, 10.5)
log M⋆ = [10.5, 11.5]
log MHI/M⋆
log sSFR [yr-1]
218 2197 8161 923
2443 3681 4875 55
3022 1313 767


full sample
log μ⋆ = [7, 8)
log μ⋆ = [8, 8.8)
log μ⋆ = [8.8, 10]
log MHI/M⋆
log sSFR [yr-1]
49 732 6278 753
997 4454 6501 180
4632 2000 973 38