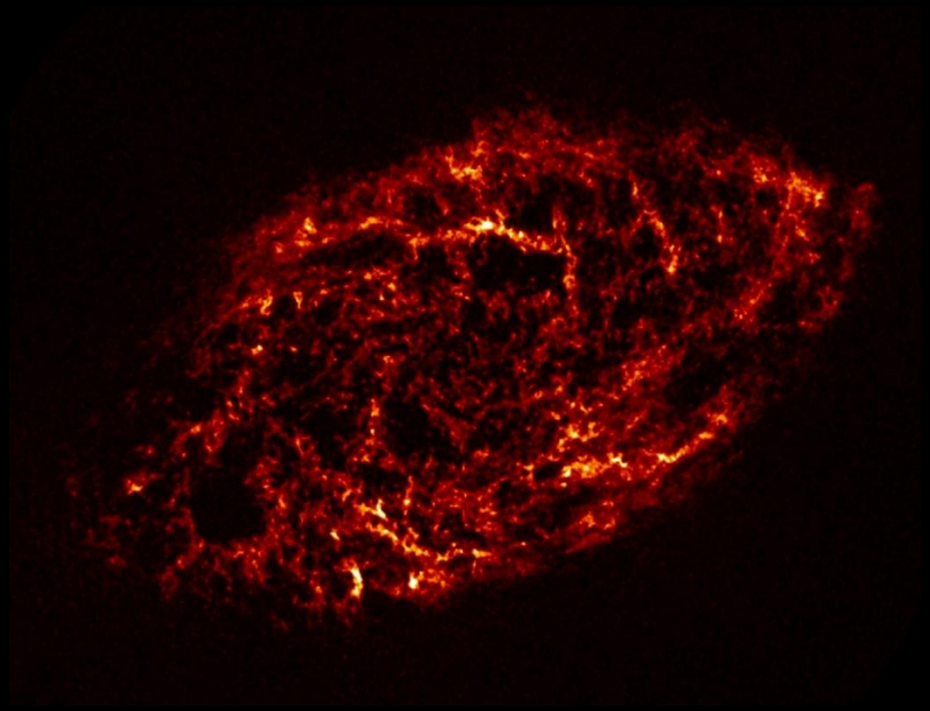
Fuel Efficient Galaxies: Sustaining Star Forming Disks with Gas Recycling

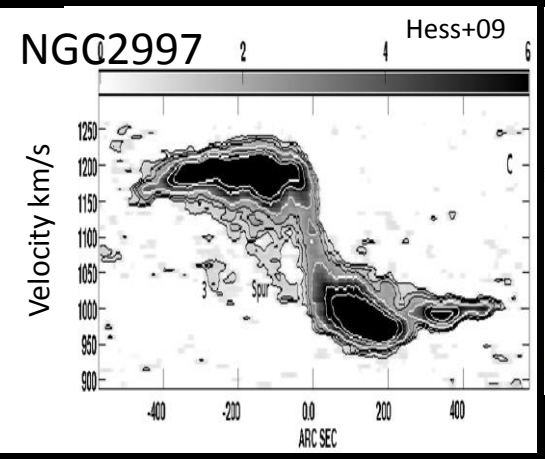


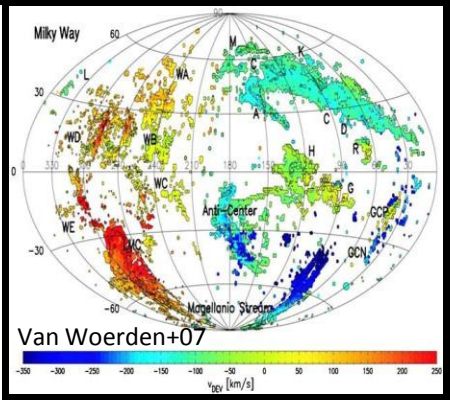
Sam Leitner (University of Chicago)

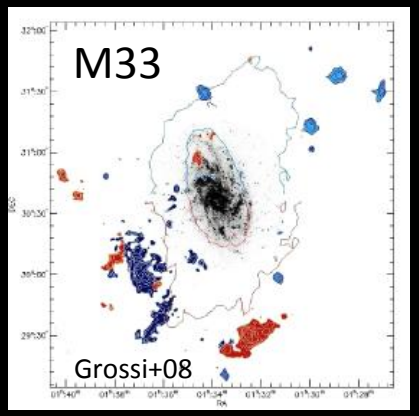
with Andrey Kravtsov

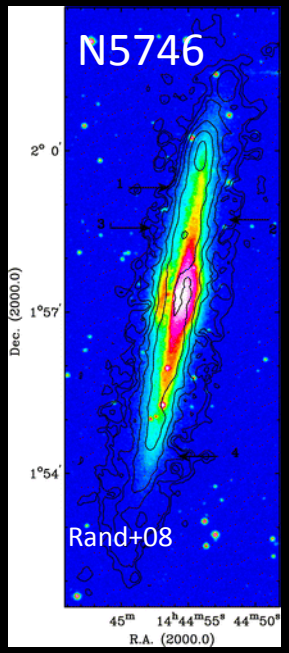
Santa Cruz Galaxy Workshop, August 20th, 2010

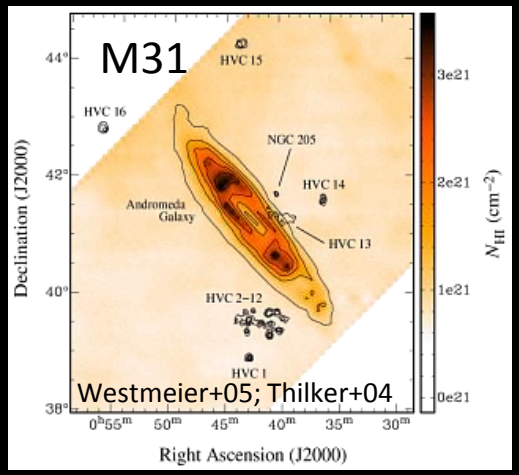
Accretion and the Gas Budget

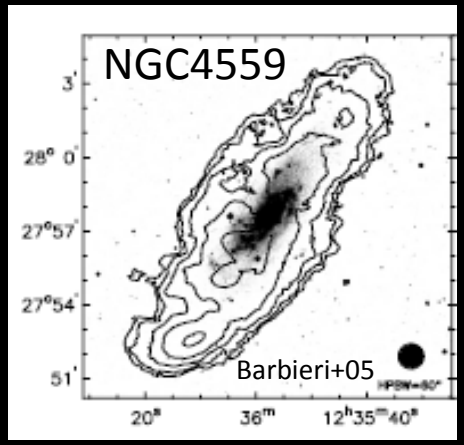




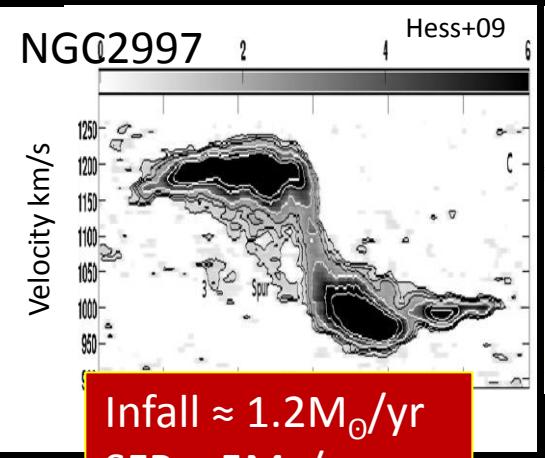




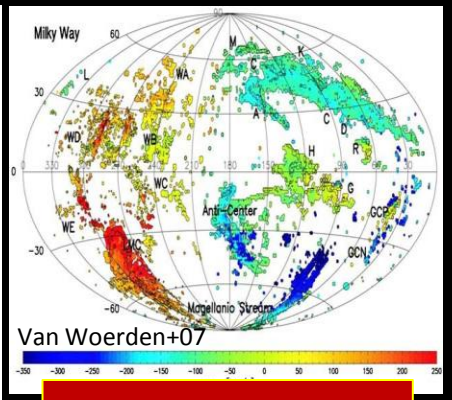




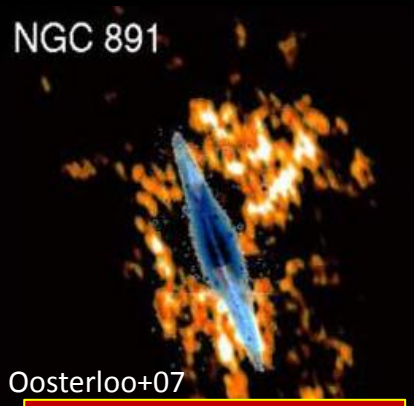
Accretion and the Gas Budget



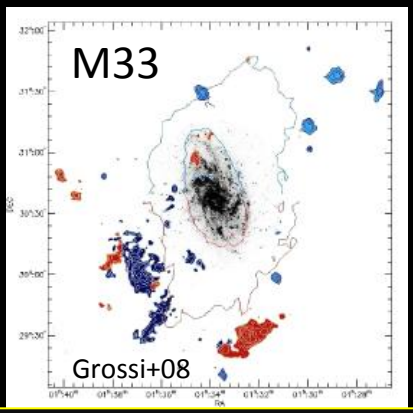
Infall ≈ 1.2$M_\odot$/yr
SFR ≈ 5$M_\odot$/yr



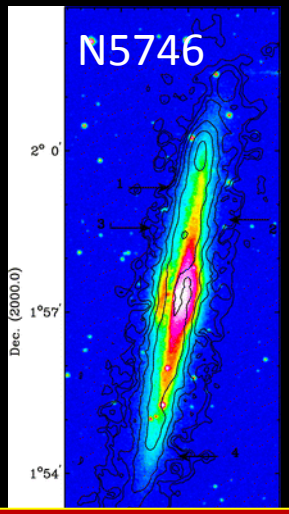
Infall ≈ 0.2$M_\odot$/yr
SFR≈1.5$M_\odot$/yr



Infall ≈ 0.2$M_\odot$/yr
SFR ≈ 3.8$M_\odot$/yr

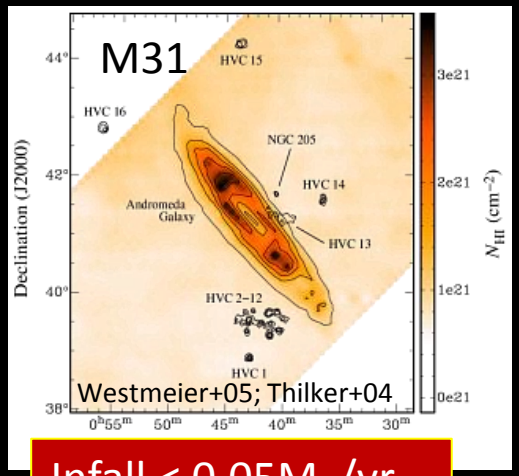


Infall ≈ 0.05-0.8$M_\odot$/yr
SFR ≈ 0.6$M_\odot$/yr

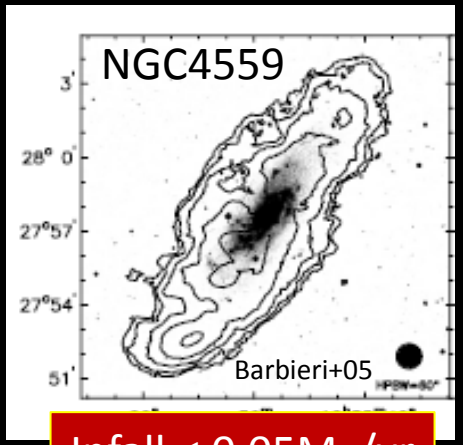


Infall ≈ 0.2$M_\odot$/yr
SFR ≈ 1$M_\odot$/yr

Infall ≈ 0.1$M_\odot$/yr
SFR ≈1.3$M_\odot$/yr



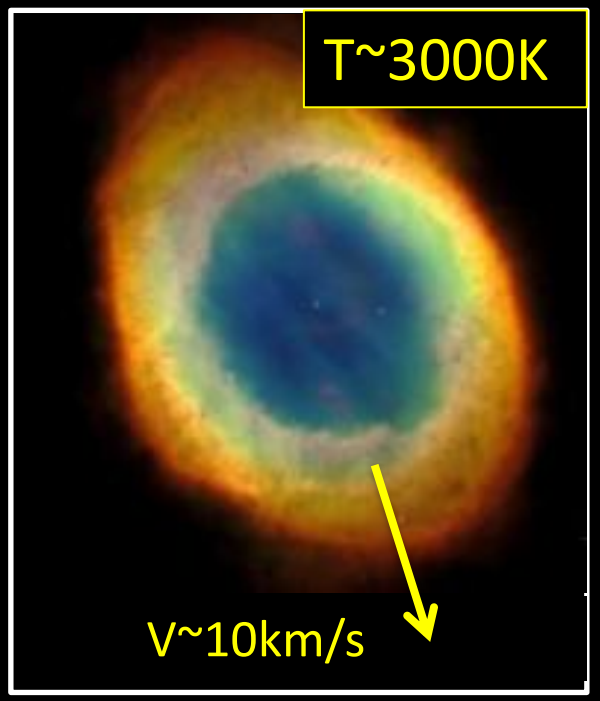
Infall < 0.05$M_\odot$/yr
SFR ≤1.0$M_\odot$/yr



Infall < 0.05$M_\odot$/yr
SFR ≈ 0.6$M_\odot$/yr

Stars: Galactic Recyclers

- A stellar population returns 30-50% of its mass in 10Gyr.
- Most gas is returned cold and low velocity.
- Stars shed gas and form in similar places.



Reference

Method

1. Star Formation Histories -> population ages
2. Mass loss model
3. Reprocessing model

Importance of Gas Reprocessing to Star Formation Rate Budget

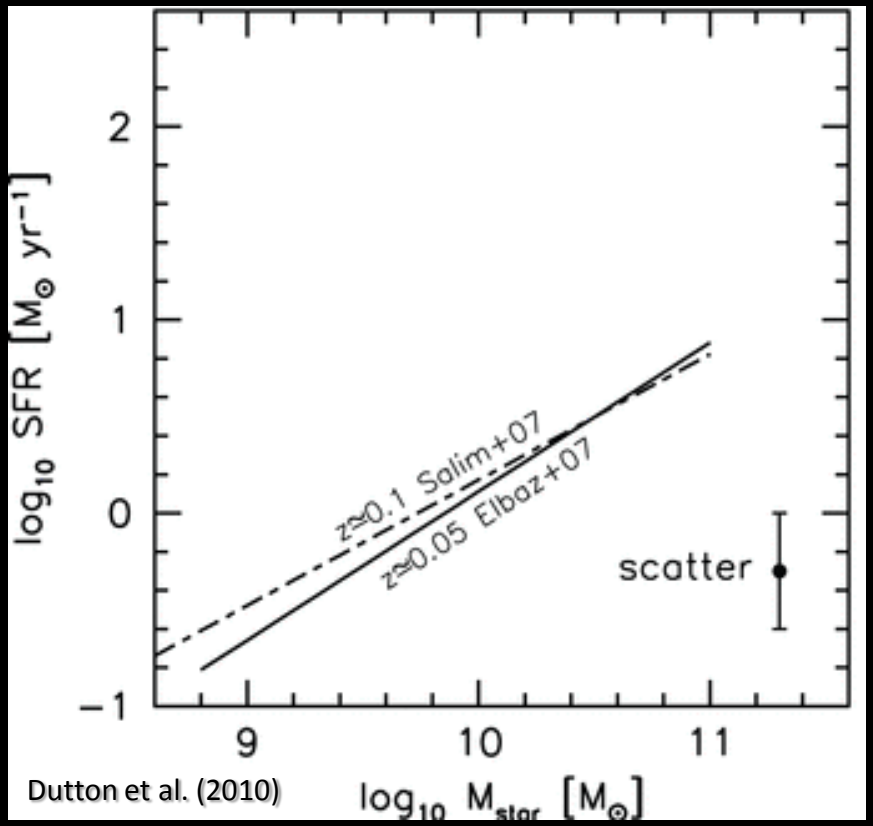
Method

1. Star Formation Histories -> population ages
2. Mass loss model
3. Reprocessing model

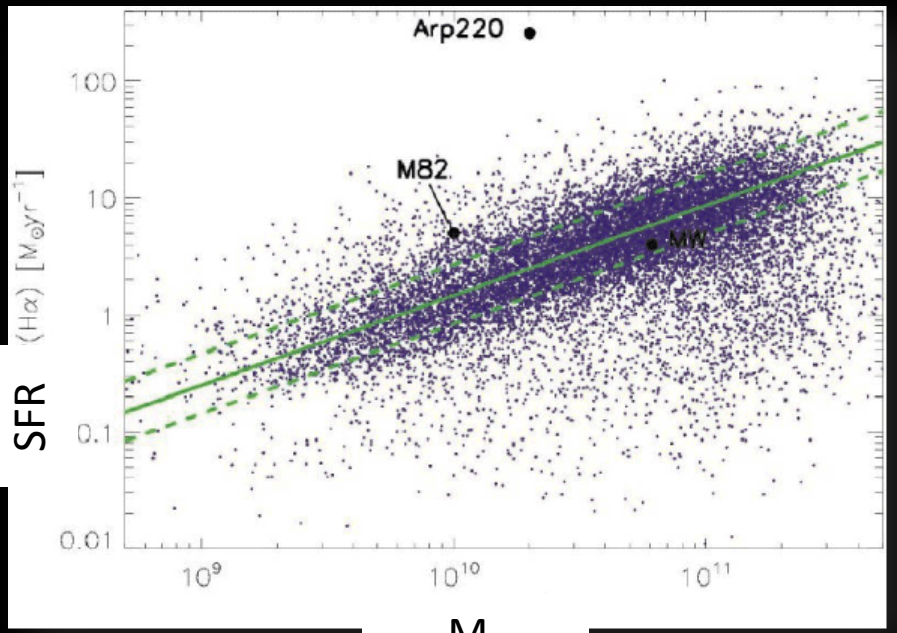
Importance of Gas Reprocessing to Star Formation Rate Budget

The SFR Sequence

- Tight sequence of star formers: SFR-M_*



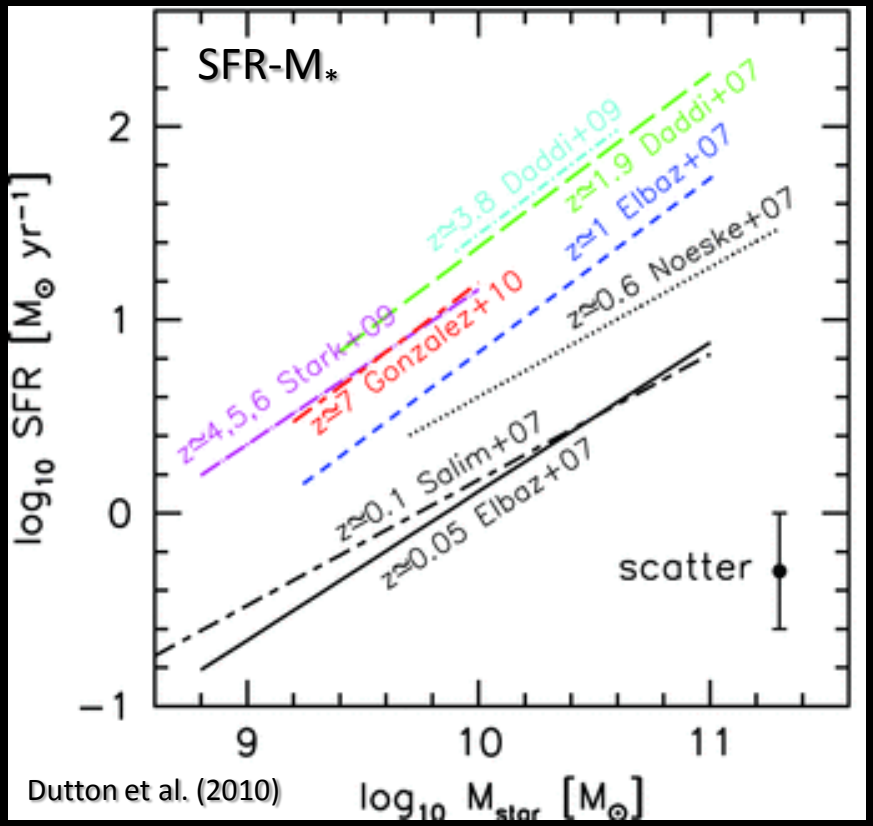
Dutton et al. (2010)



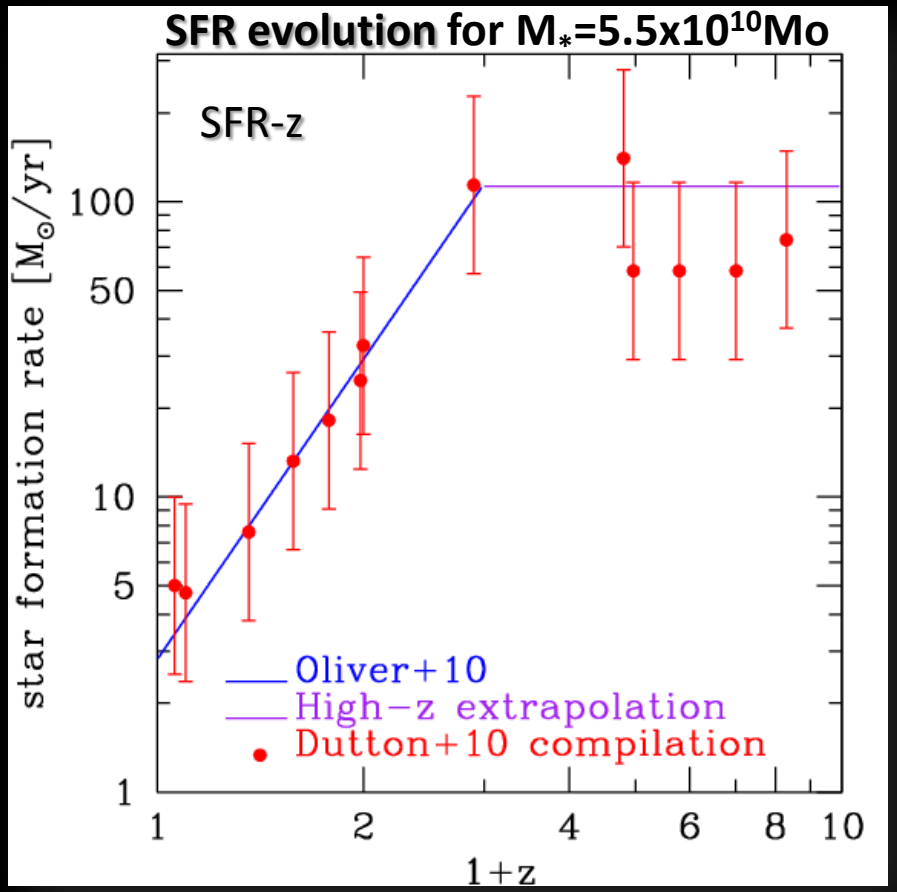
Elbaz+07

“Un-Integrating” Stellar Mass

- Tight sequence of star formers: SFR-M_*, persists to high redshift.
- Start with M_* step back in time, removing stellar mass according to $SFR(M_*,z)=A_0(z+1)^{\alpha}(M^*/M_0)^{\beta}$ (modulo mass loss).

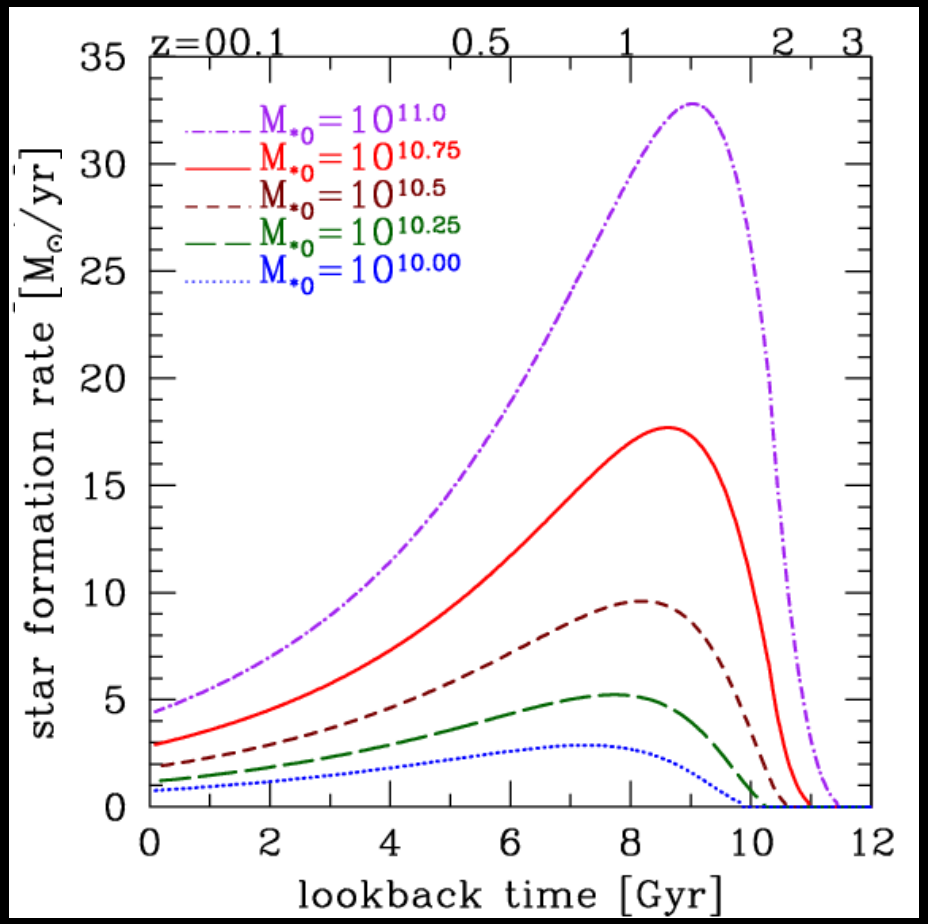


Dutton et al. (2010)

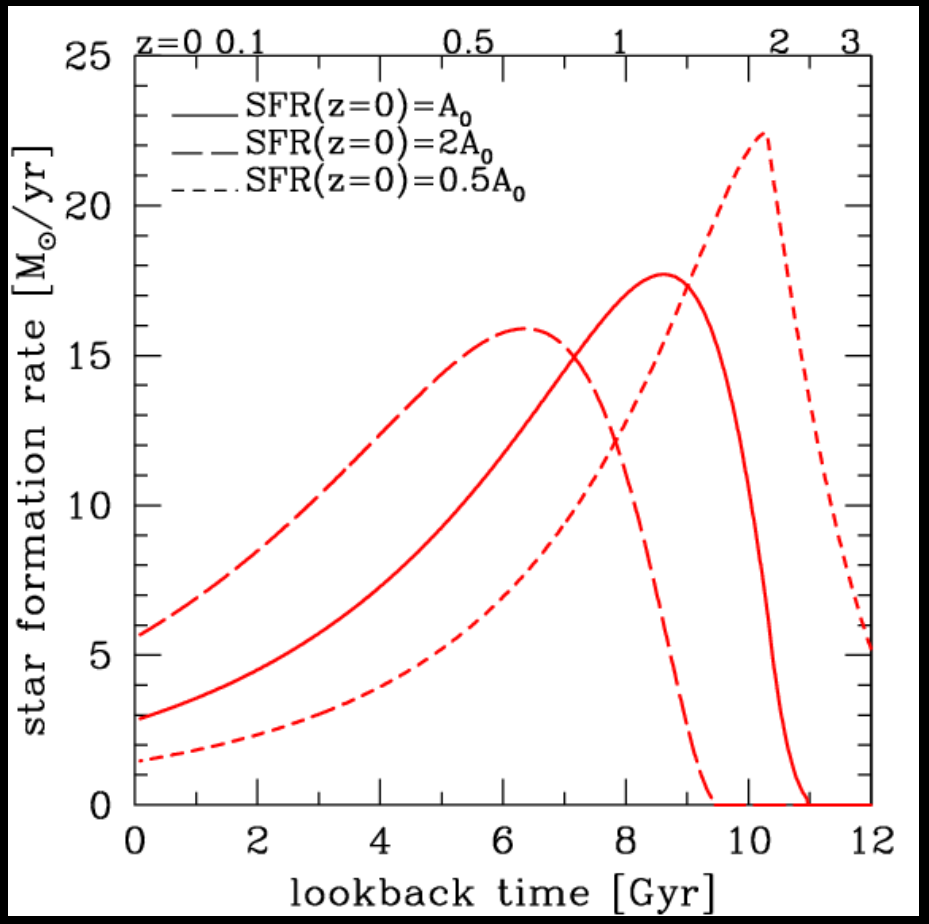


Star Formation Histories

At the median star formation rate for various $M_*(z=0)$



At fixed $M_*(z=0)$ for various z=0 star formation rates.



Method

1. Star Formation Histories -> population ages
   - From empirical star formation scaling relations.
2. Mass loss model

3. Reprocessing model

Importance of Gas Reprocessing to Star Formation Rate Budget

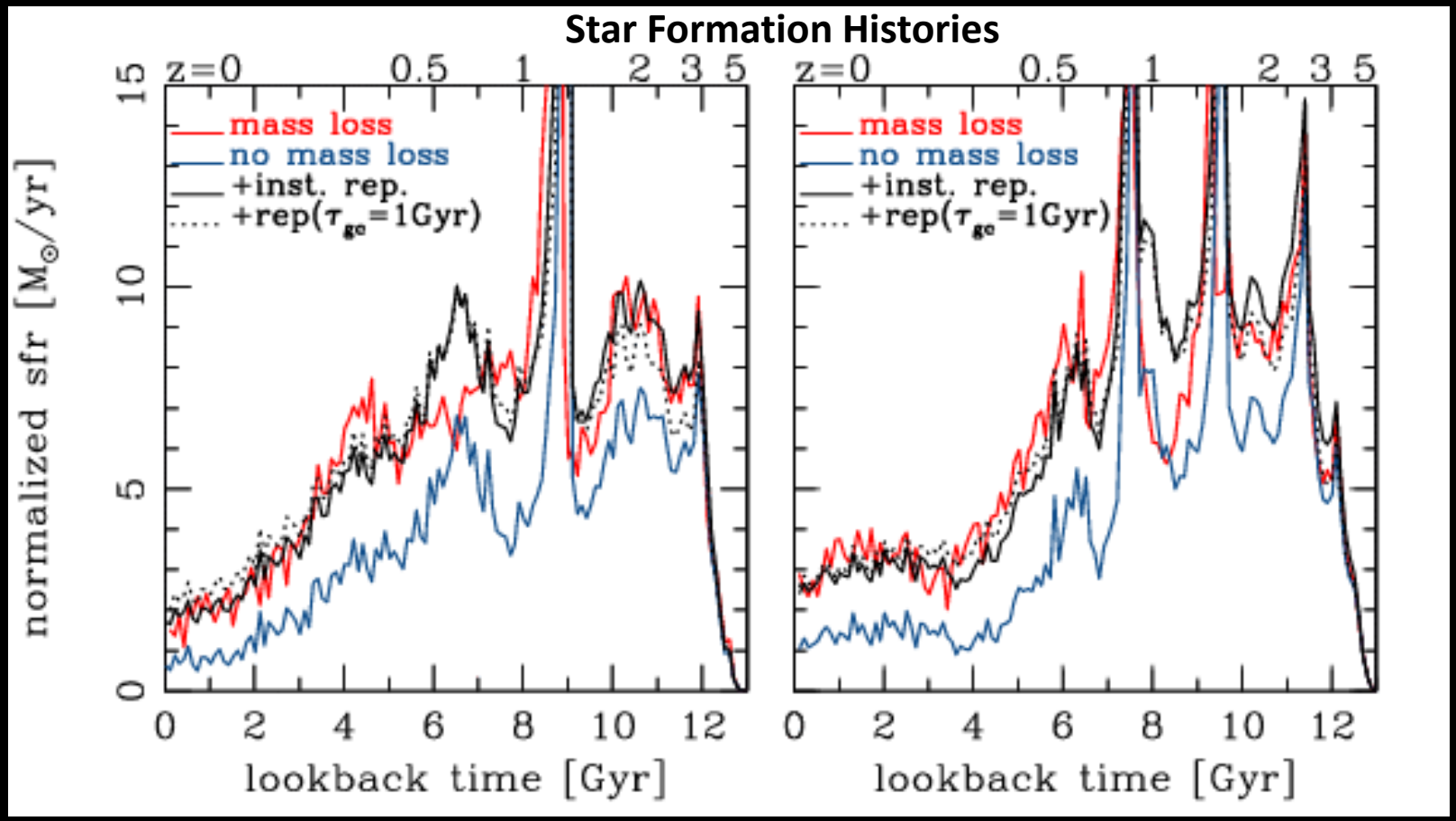
Method

1. Star Formation Histories -> population ages
   - From empirical star formation scaling relations.
2. Mass loss model
   - From stellar evolution models + IMF.
3. Reprocessing model

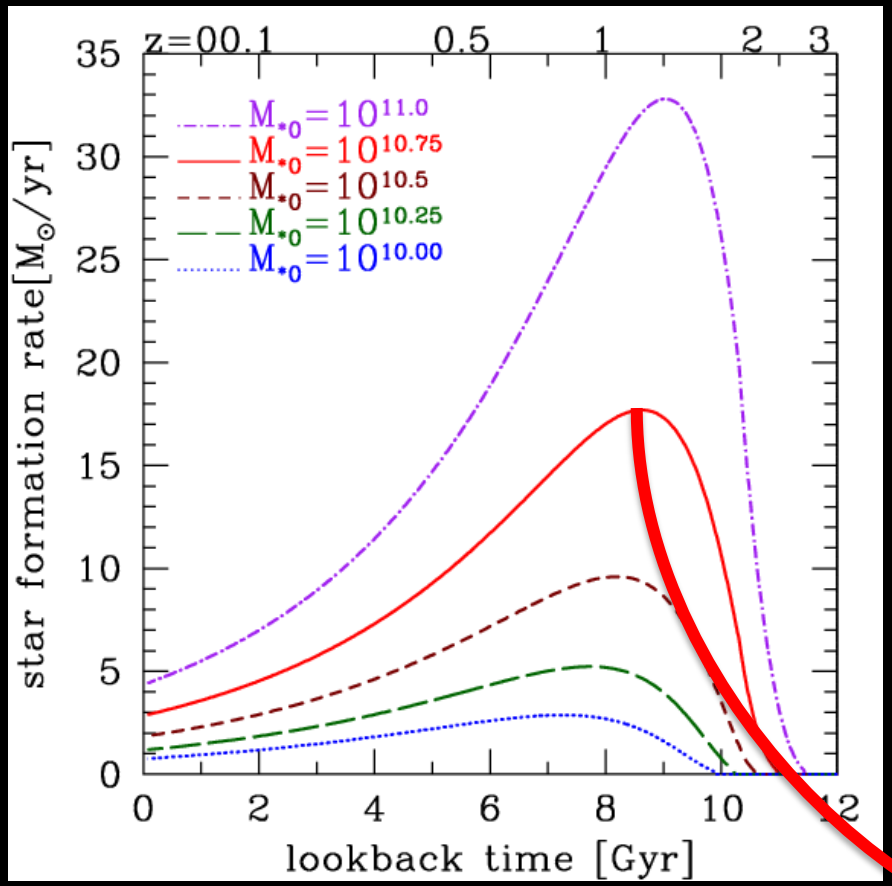
Importance of Gas Reprocessing to Star Formation Rate Budget

Gas Reprocessing Model

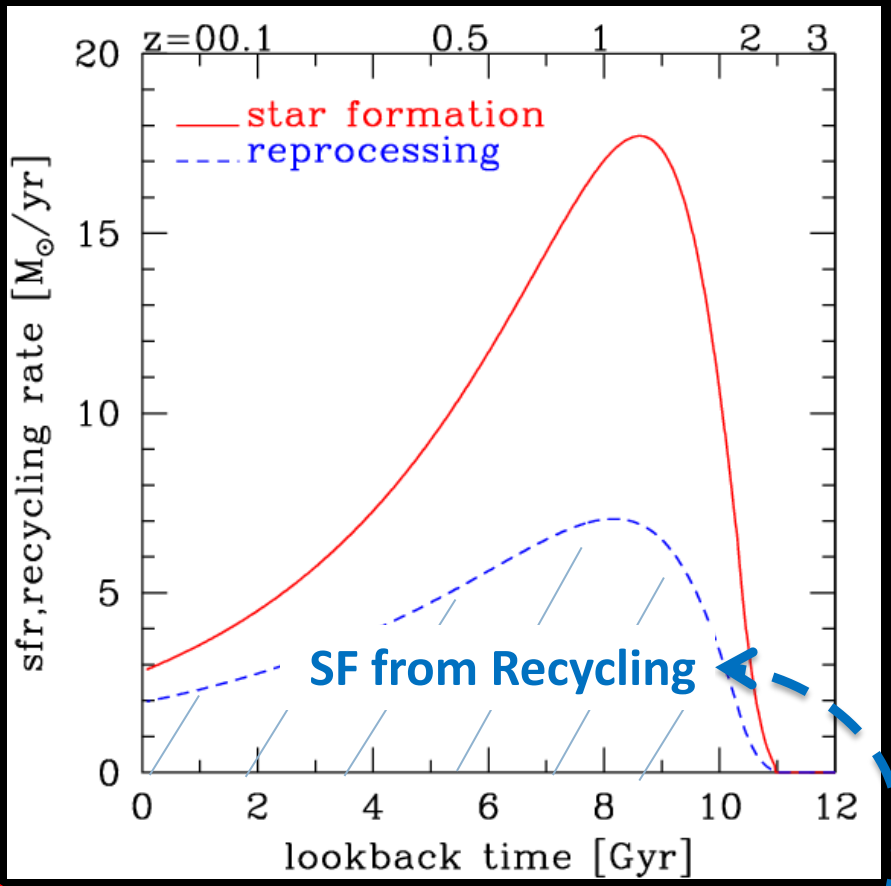
- Simulated Milky Way Mass Halos demonstrate that the instant reprocessing of lost stellar material accounts for additional star formation.



Star Formation Histories



Reprocessing Contribution



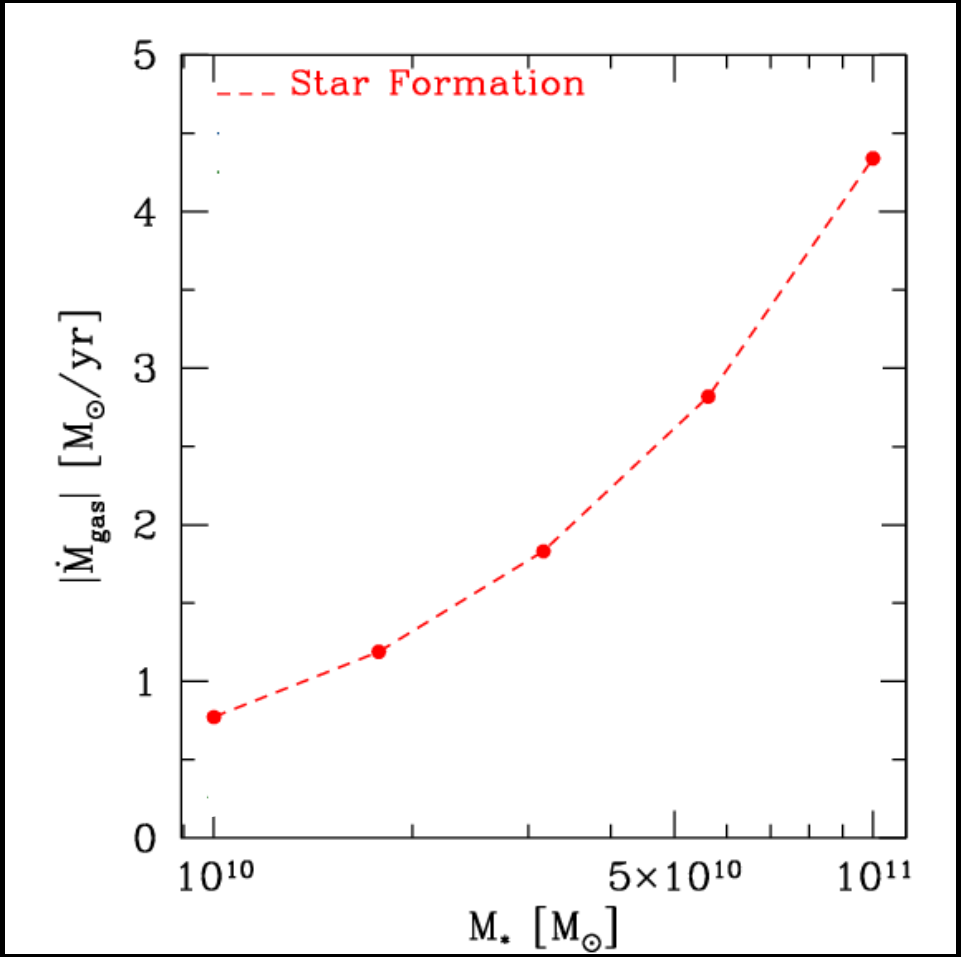
Recycling Model

Method

1. Star Formation Histories -> population ages
   - From empirical star formation scaling relations.
2. Mass loss model
   - From stellar evolution models + IMF.
3. Reprocessing model
   - From simulation

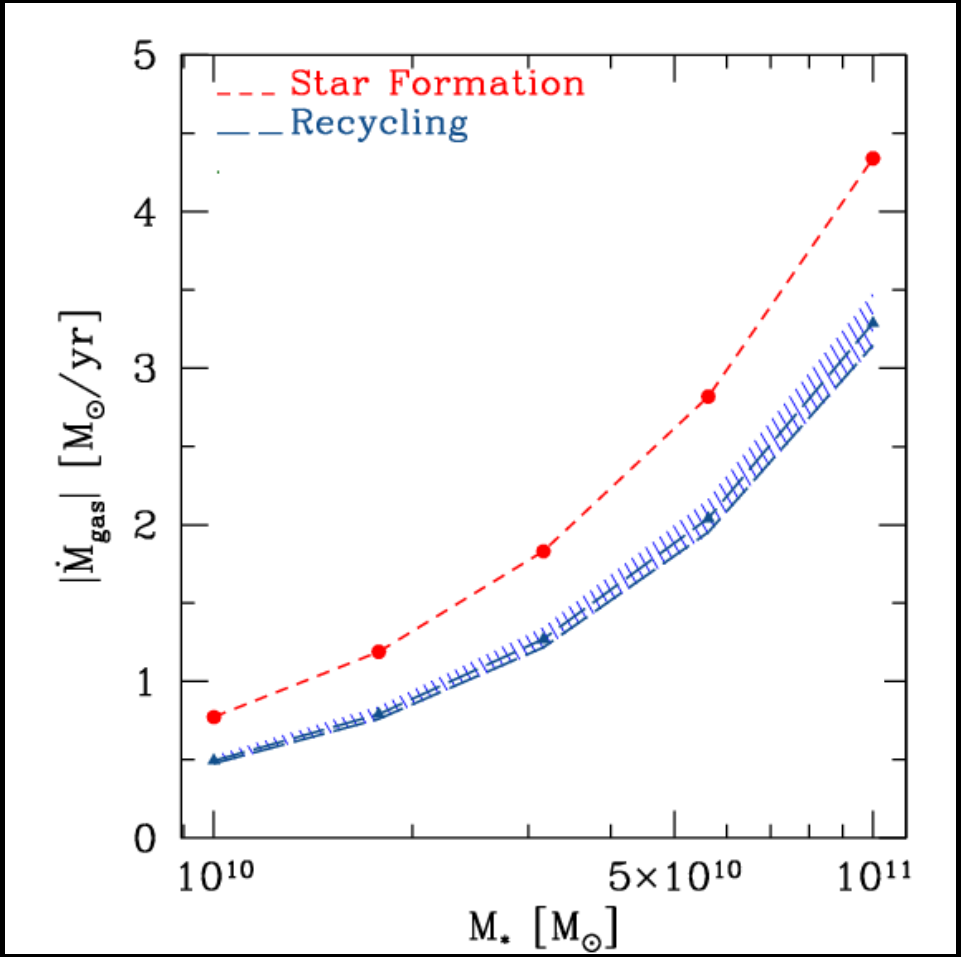
Importance of Gas Reprocessing to Star Formation Rate Budget

z=0 Reprocessing Predictions



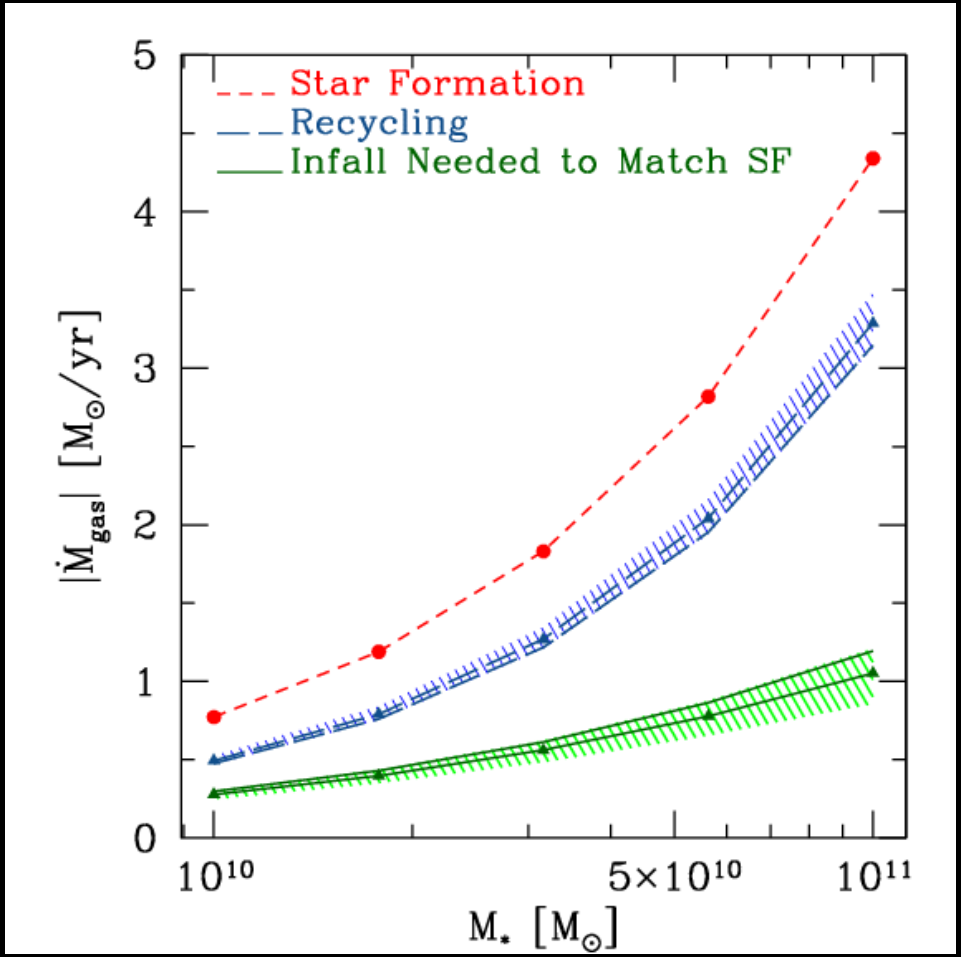
- Median star formation rate as a function of M_*.

z=0 Reprocessing Predictions



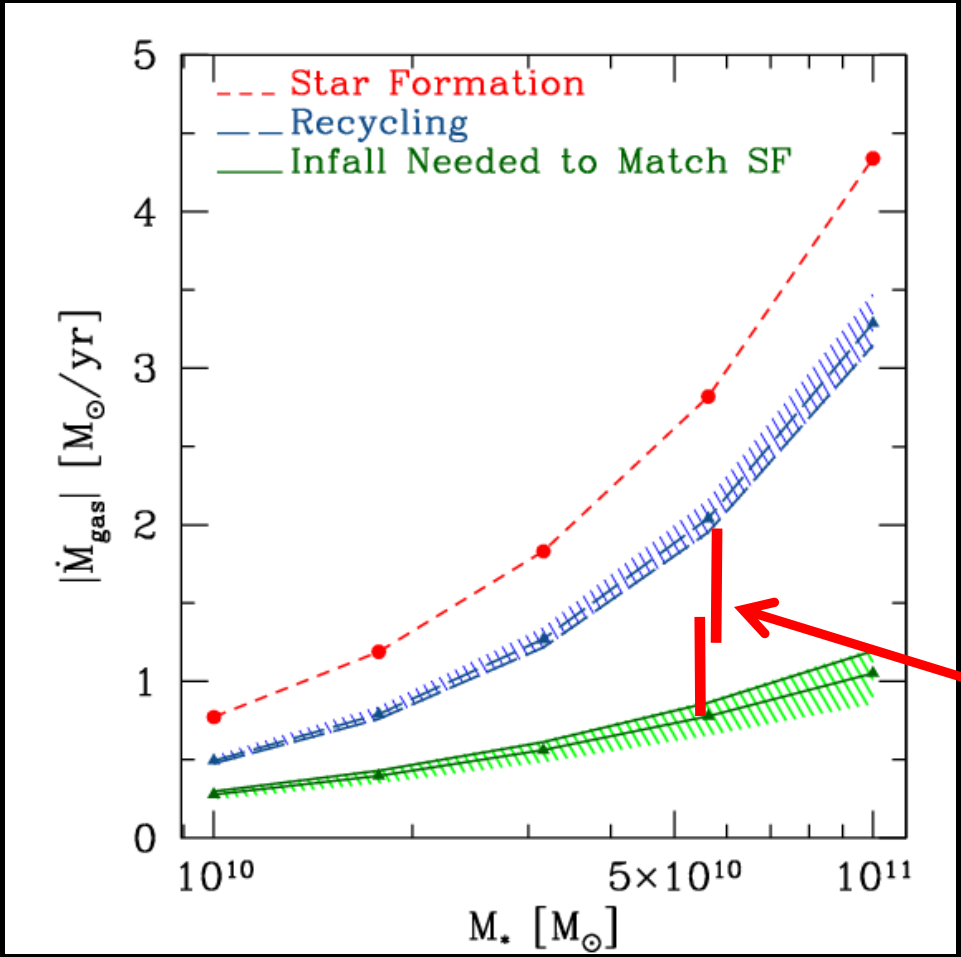
- Median star formation rate as a function of M_*.
- Recycling rate for galaxies with median star formation rates as a function of M_* including modeling uncertainty

z=0 Reprocessing Predictions



- Median star formation rate as a function of M_*.
- Recycling rate for galaxies with median star formation rates as a function of M_* including modeling uncertainty
- Accretion rate needed to replenish the gas disk (from HI infall?)

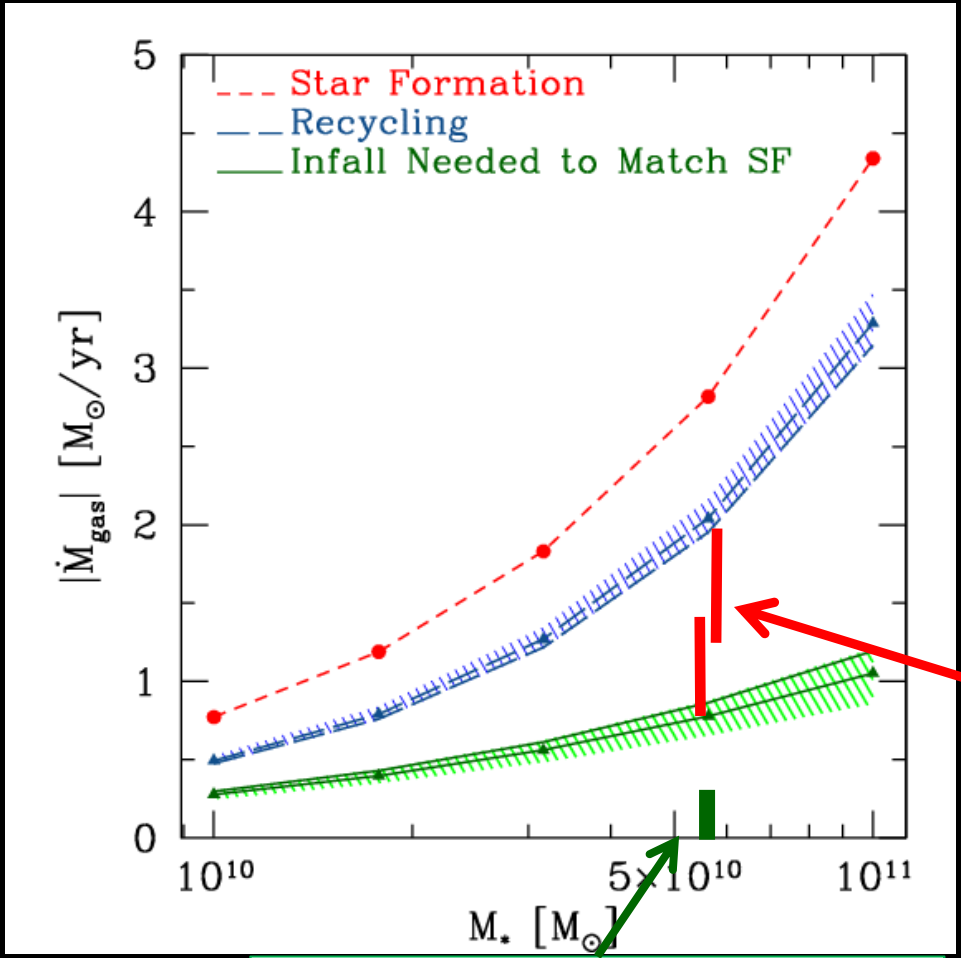
z=0 Reprocessing Predictions



- Median star formation rate as a function of M_*.
- Recycling rate for galaxies with median star formation rates as a function of M_* including modeling uncertainty
- Accretion rate needed to replenish the gas disk (from HI infall?)

Most recent Milky Way star formation rate measurements.
(Murray & Rahman 2010,Robitaille & Whitney 2010)

z=0 Reprocessing Predictions

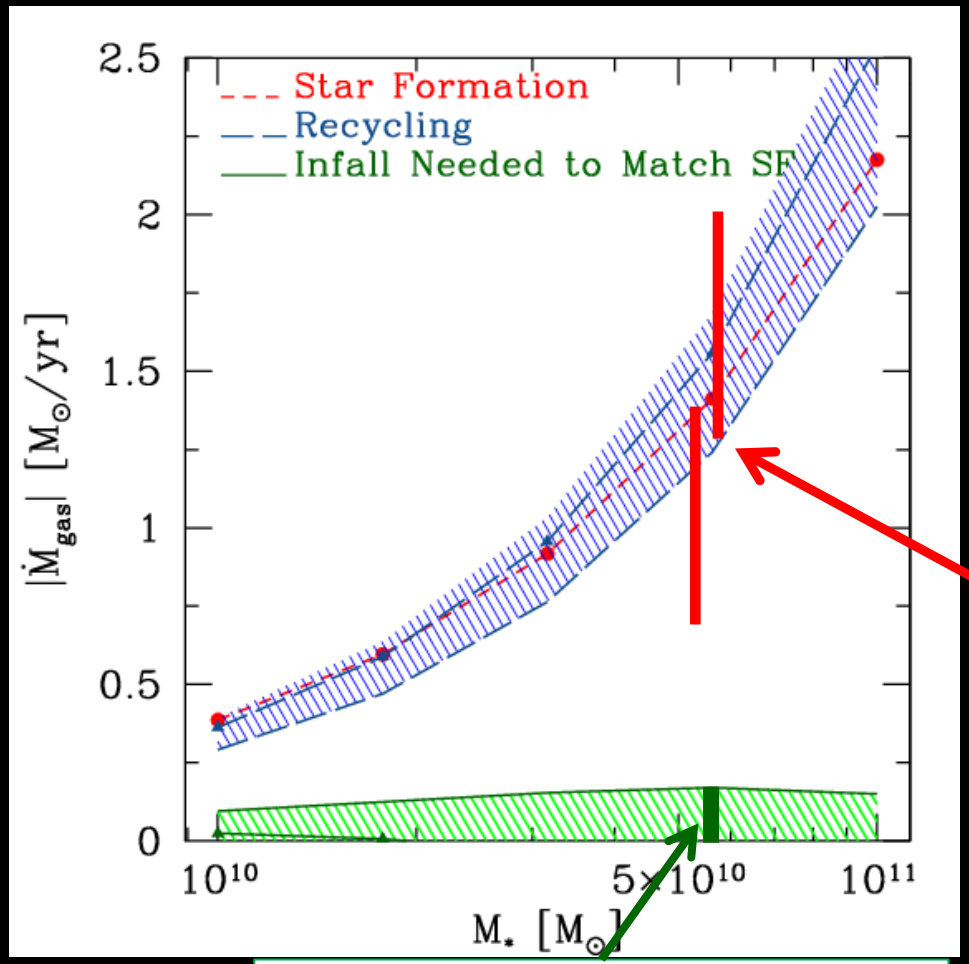


- Median star formation rate as a function of M_*.
- Recycling rate for galaxies with median star formation rates as a function of M_* including modeling uncertainty
- Accretion rate needed to replenish the gas disk (from HI infall?)

Milky Way infall needed at observed SFR

Most recent Milky Way star formation rate measurements. (Murray & Rahman 2010,Robitaille & Whitney 2010)

z=0 Reprocessing Predictions

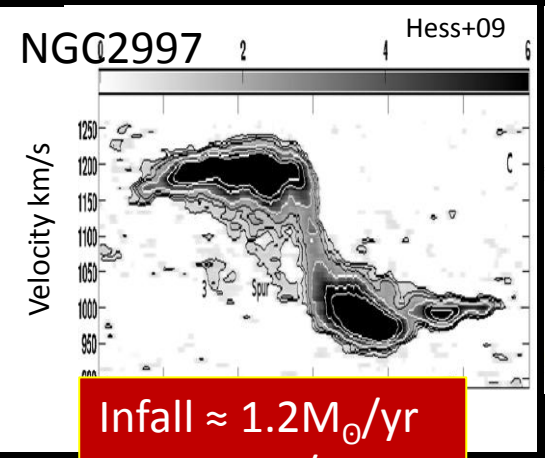


- 0.5*median star formation rate as a function of M_*.
- Recycling rate for galaxies with 0.5*median star formation rates as a function of M_* including modeling uncertainty
- Accretion rate needed to replenish the gas disk (from HI infall?)

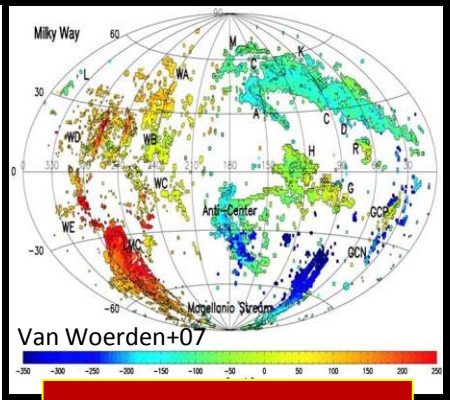
Most recent Milky Way star formation rate measurements. (Murray & Rahman 2010,Robitaille & Whitney 2010)

Milky Way infall needed at observed SFR

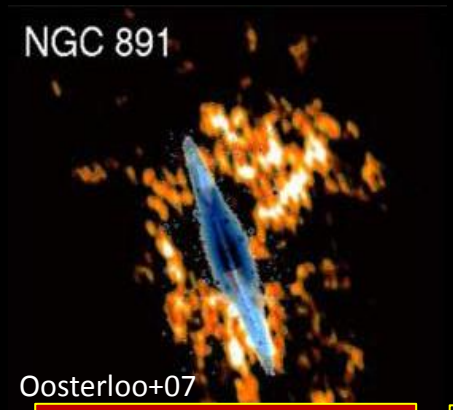
Accretion and the Gas Budget



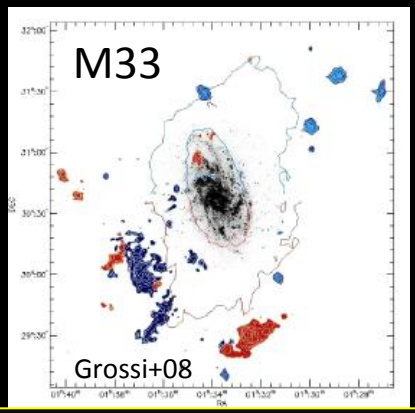
Infall ≈ 1.2$M_\odot$/yr
SFR ≈ 5$M_\odot$/yr



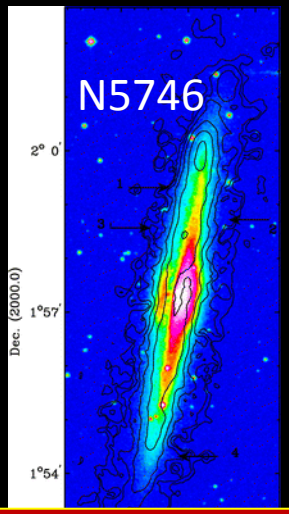
Infall ≈ 0.2$M_\odot$/yr
SFR≈1.5$M_\odot$/yr



Infall ≈ 0.2$M_\odot$/yr
SFR ≈ 3.8$M_\odot$/yr

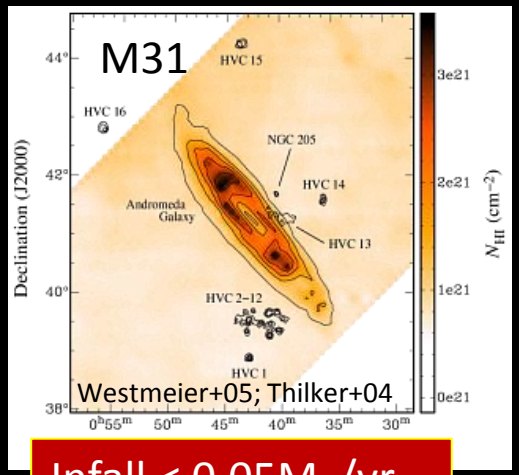


Infall ≈ 0.05-0.8$M_\odot$/yr
SFR ≈ 0.6$M_\odot$/yr

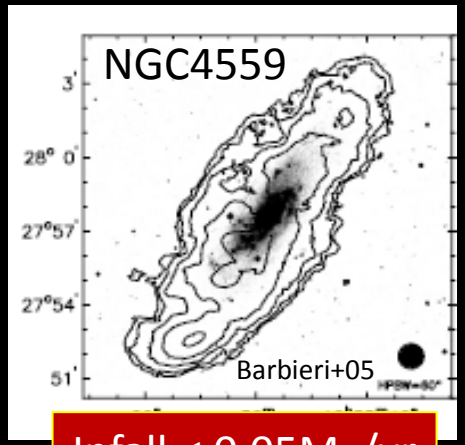


Infall ≈ 0.2$M_\odot$/yr
SFR ≈ 1$M_\odot$/yr

Infall ≈ 0.1$M_\odot$/yr
SFR ≈1.3$M_\odot$/yr

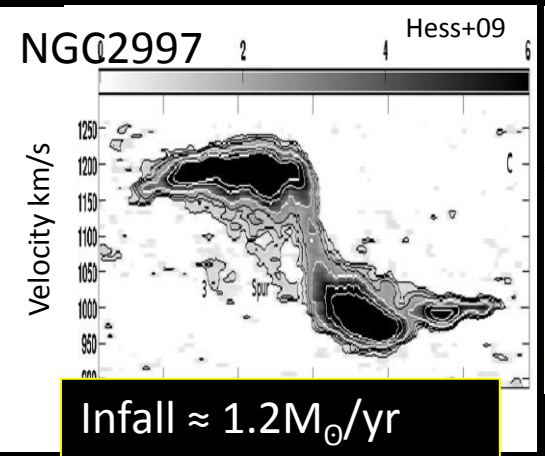


Infall < 0.05$M_\odot$/yr
SFR ≈ ≤ 1.0$M_\odot$/yr

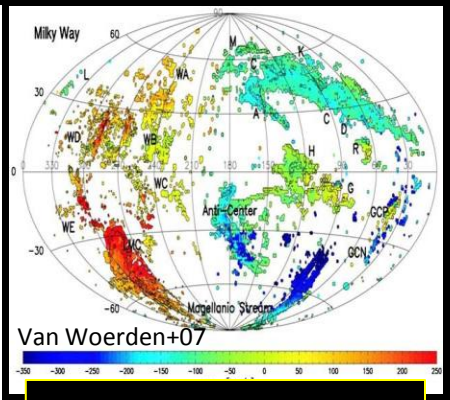


Infall < 0.05$M_\odot$/yr
SFR ≈ 0.6$M_\odot$/yr

The Gas Budget Including Recycling

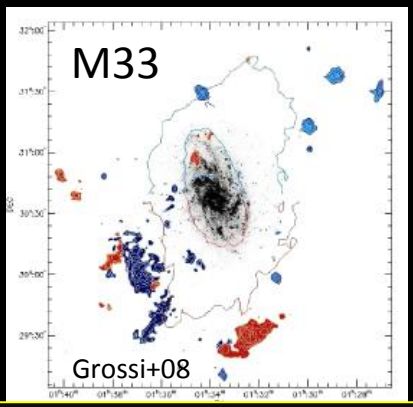


Infall ≈ 1.2$M_\odot$/yr
Reproc ≈ 4.5 $M_\odot$/yr
SFR ≈ 5 $M_\odot$/yr

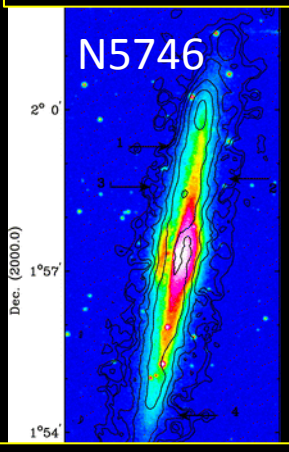


Infall ≈ 0.2$M_\odot$/yr
Reproc ≈1.4$M_\odot$/yr
SFR ≈ 1.5$M_\odot$/yr

Infall ≈ 0.2$M_\odot$/yr
Reproc ≈3.1$M_\odot$/yr
SFR ≈ 3.8$M_\odot$/yr

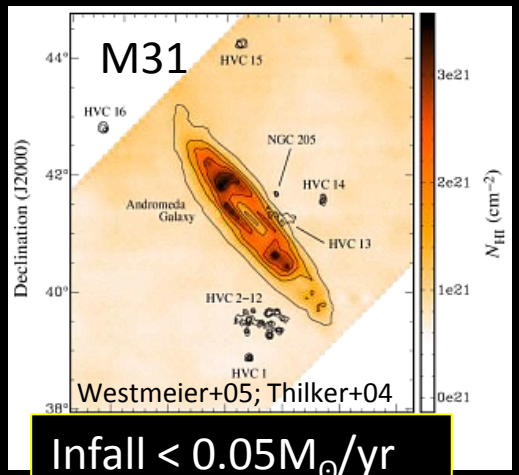


Infall ≈ 0.05-0.8$M_\odot$/yr
Reproc ≈ 0.35$M_\odot$/yr
SFR ≈ 0.6$M_\odot$/yr

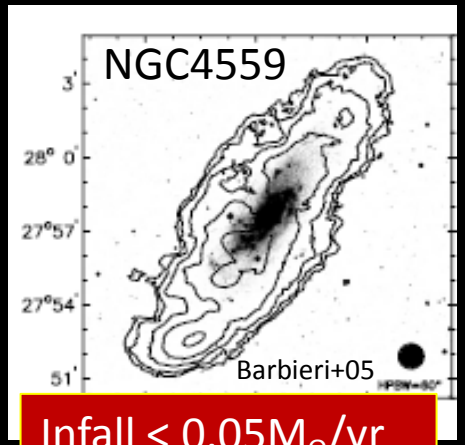


Infall ≈ 0.2$M_\odot$/yr
Reproc≈2.6$M_\odot$/yr
SFR ≈ 1$M_\odot$/yr

Infall ≈ 0.1$M_\odot$/yr
Reproc ≈ 0.75$M_\odot$/yr
SFR ≈ 1.3$M_\odot$/yr

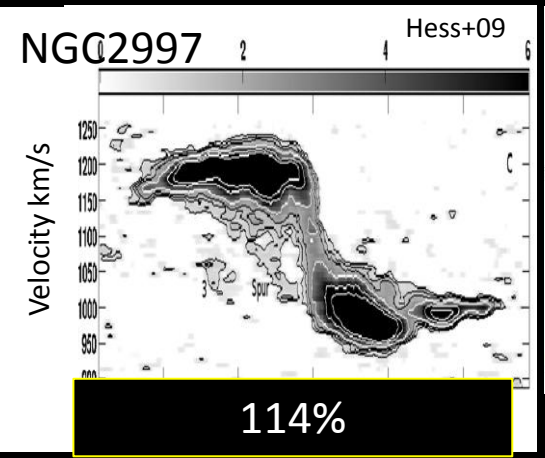


Infall < 0.05$M_\odot$/yr
Reproc ≈ 1.8$M_\odot$/yr
SFR ≤ 1.0$M_\odot$/yr

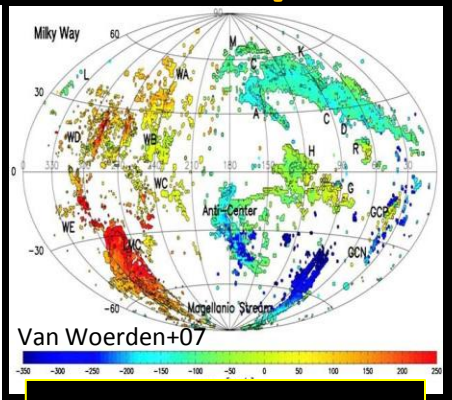


Infall < 0.05$M_\odot$/yr
Reproc ≈ 0.4$M_\odot$/yr
SFR ≈ 0.6$M_\odot$/yr

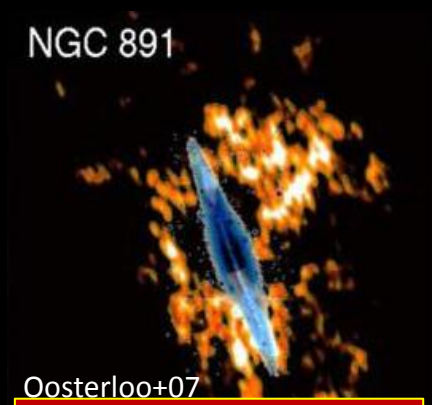
Percent of Star Formation Replenished



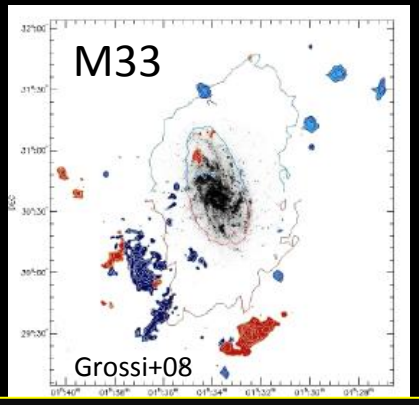
114%



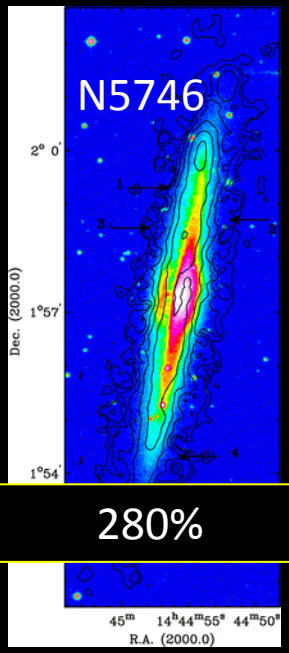
107%



87%

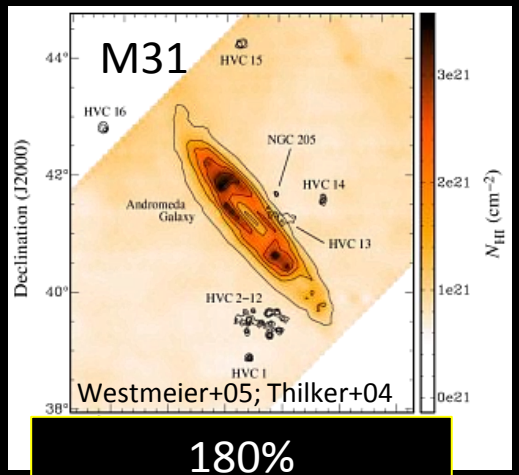


67%-190%

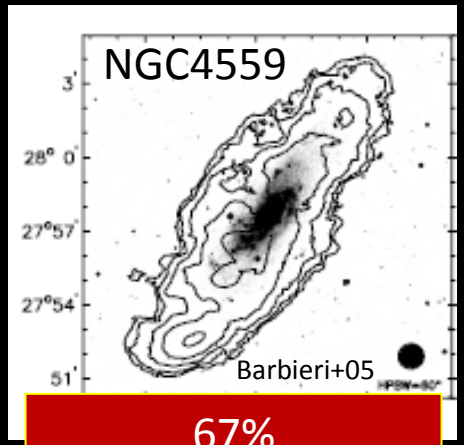


280%

65%

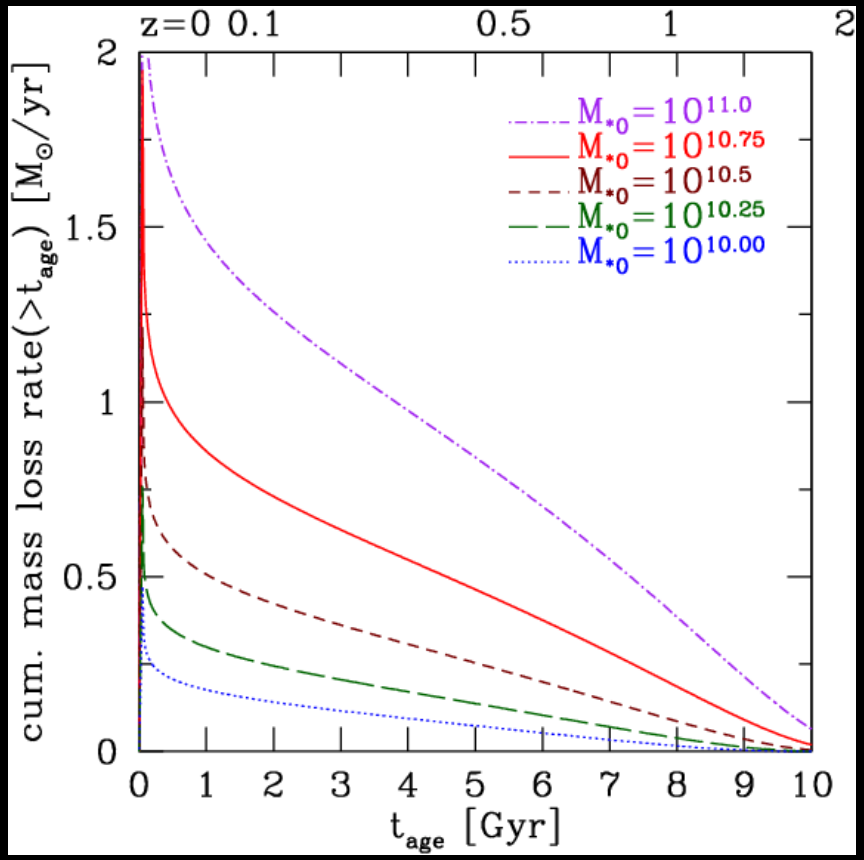


180%



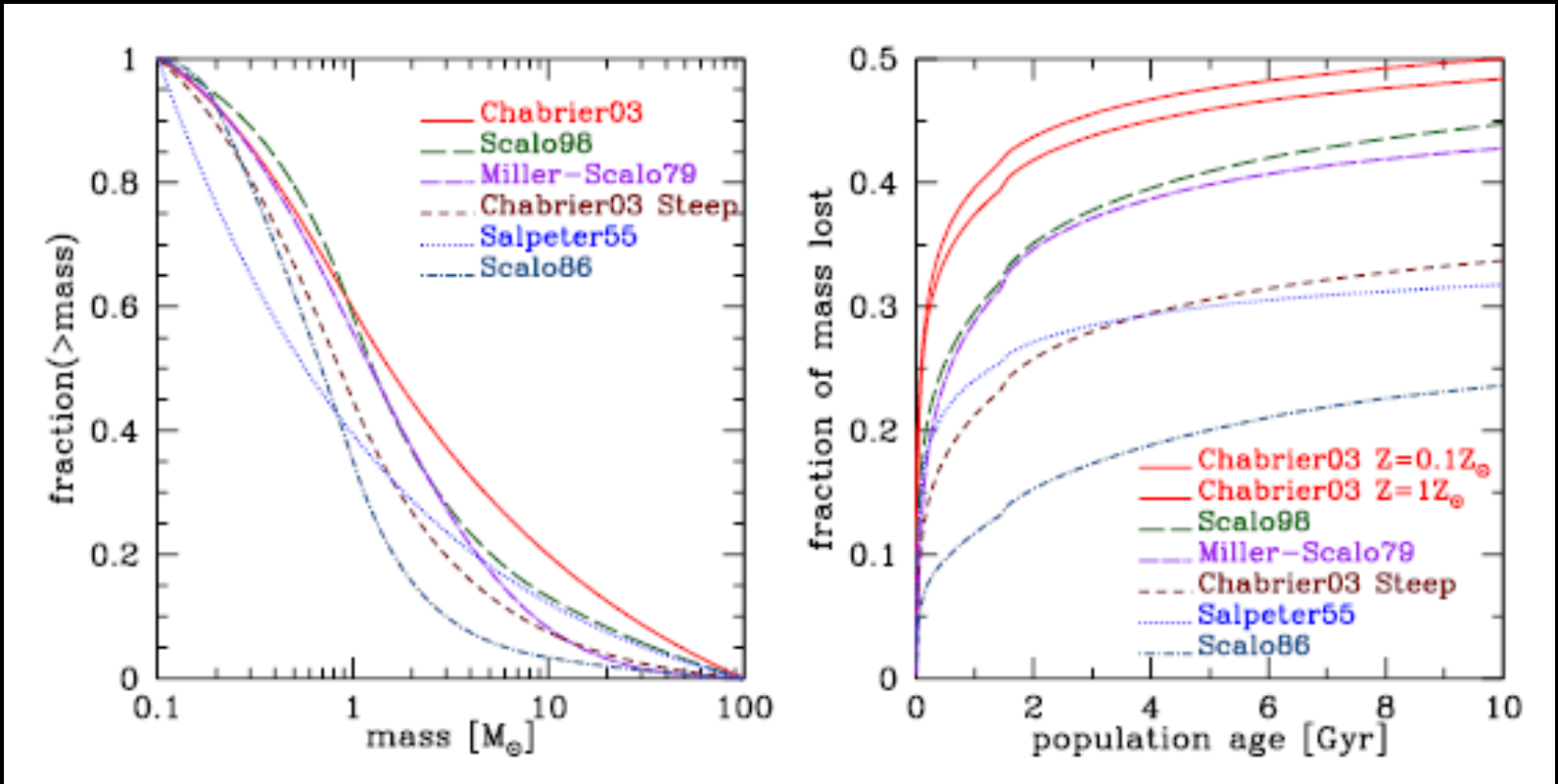
67%

The Ages of Populations that Contribute to Mass Loss at z=0

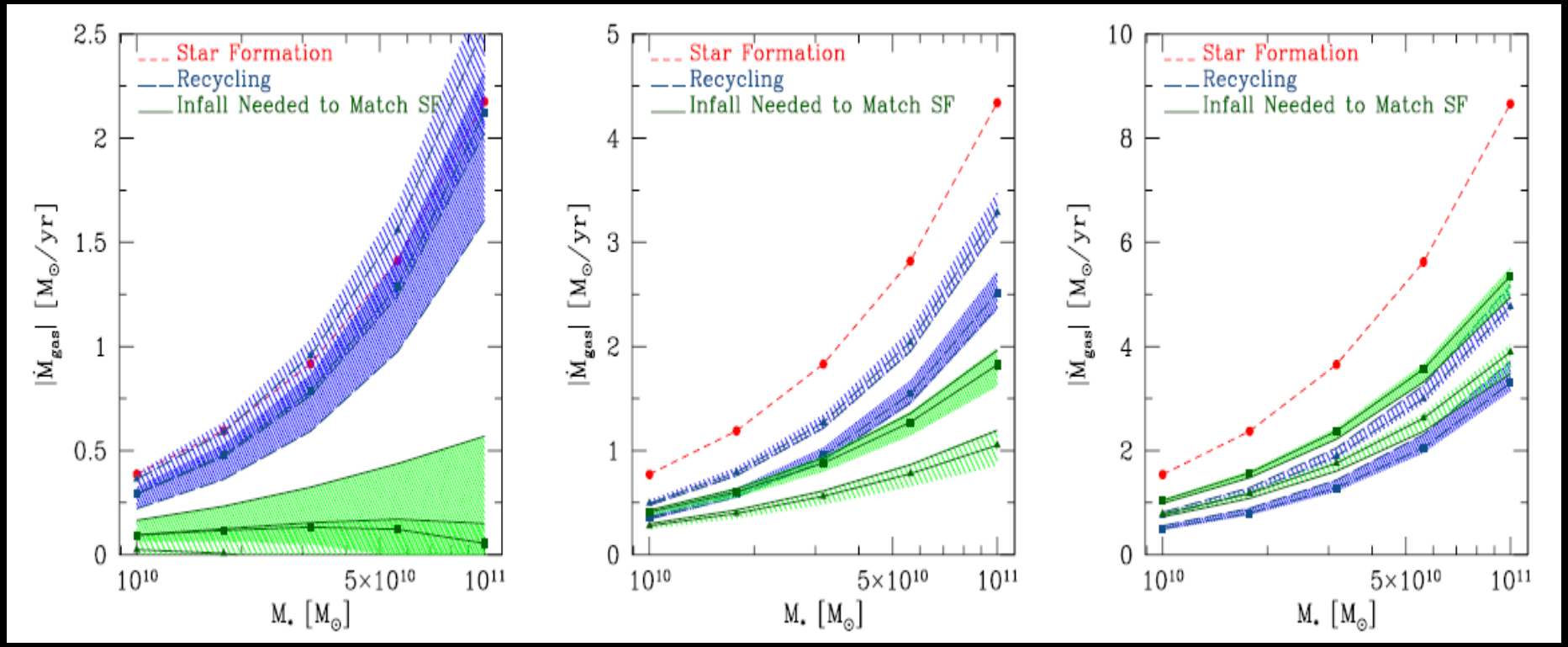


- Quenching star formation does not quench recycling.
- For a Milky Mass Galaxy (red) quenching star formation 2 Gyrs ago leaves >0.75$M_\odot$/yr of continued mass loss from older stars.

Mass Loss Dependence on IMF



Reprocessing for Different SFR(z=0)



0.5*Med(SFR(z=0))

Median Star SFR(z=0)

2*Med(SFR(z=0))

Chabrier 2003 + Salpeter High Mass Slope = light hatching

Chabrier 2003 + Steep High Mass Slope (-1.7)= dense hatching

Reprocessing Uncertainty due to Slope Uncertainties