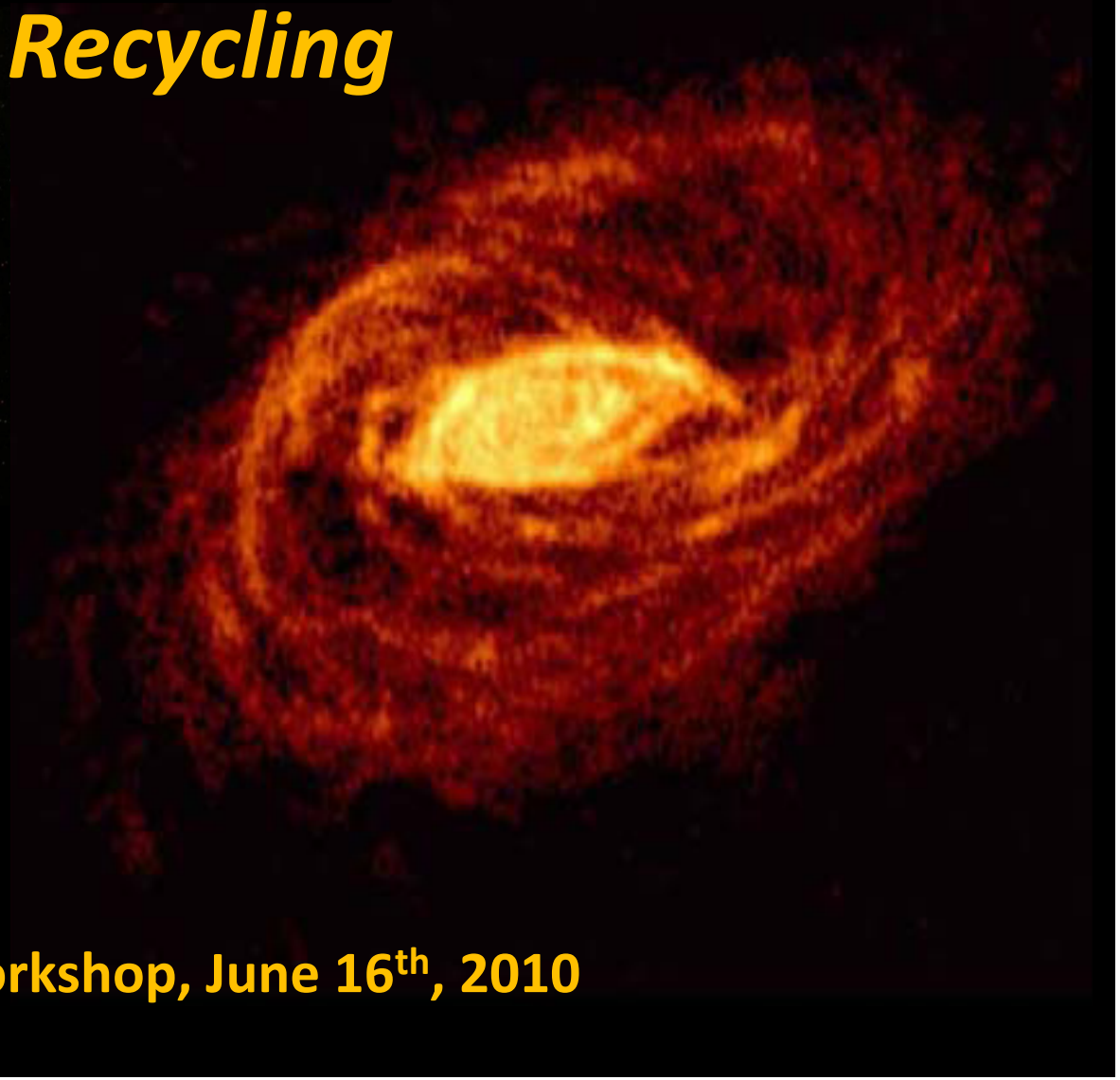
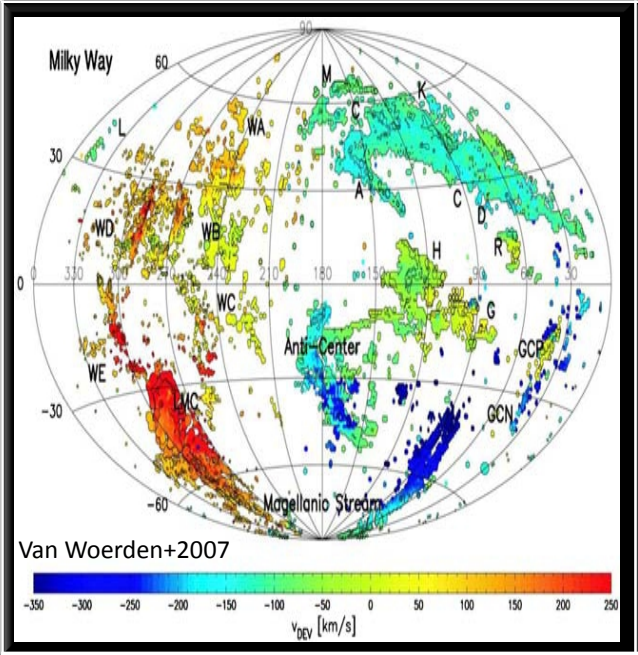
Fuel Efficient Galaxies: Sustaining Star Forming Disks with Gas Recycling



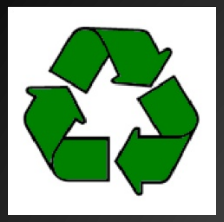
Sam Leitner
The University of Chicago
with Andrey Kravtsov

Great Lakes Cosmology Workshop, June 16th, 2010

Accretion and the Gas Budget

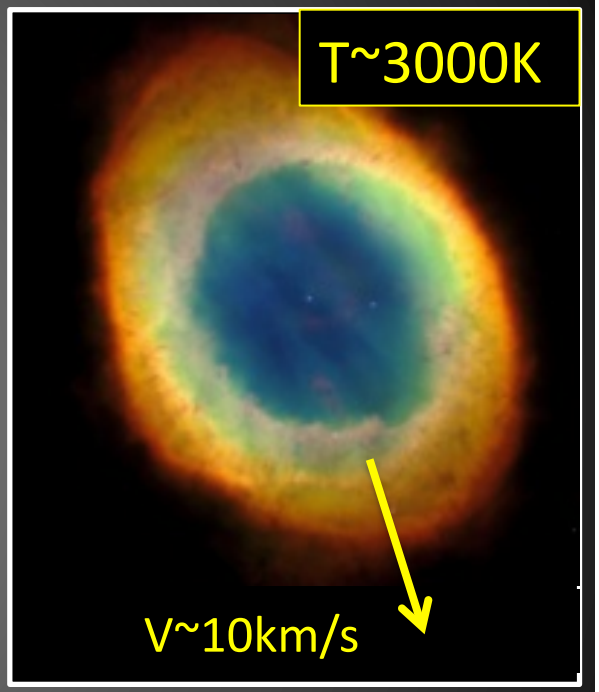


HI Infall≈0.1-.25$M_o yr^{-1}$	**HI Infall ≥0.1-0.2$M_o yr^{-1}$**	**HI Infall≈0.1-0.2$M_o yr^{-1}$**
SFR≈1.5$M_o yr^{-1}$	**SFR≈3.8$M_o yr^{-1}$**	**SFR≈1$M_o yr^{-1}$**



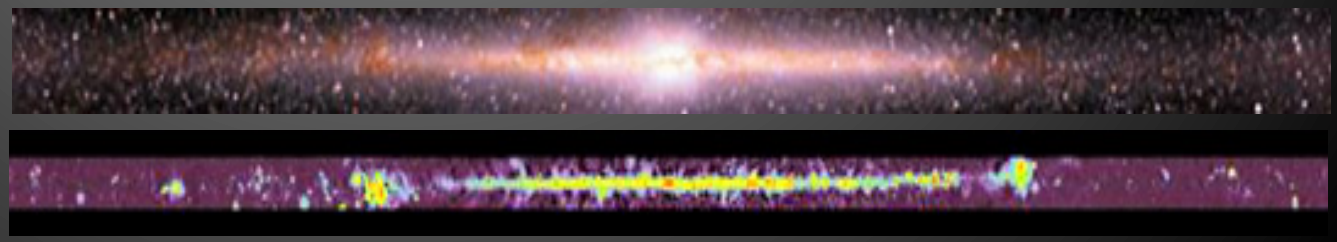
Stars: Galactic Recyclers

- A stellar population returns 40-50% of its mass in 10Gyr.
- Most gas returned is shed, cold and low velocity.
- Stars shed gas and form in similar places.



STARS (NIR)

STAR FORMATION (CO)



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

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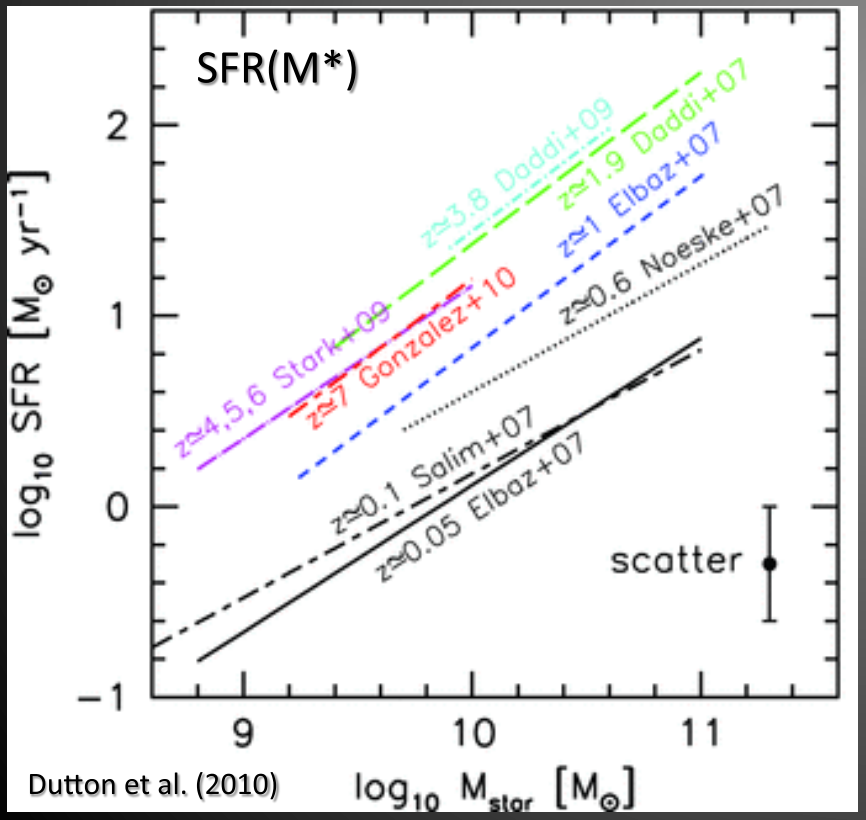
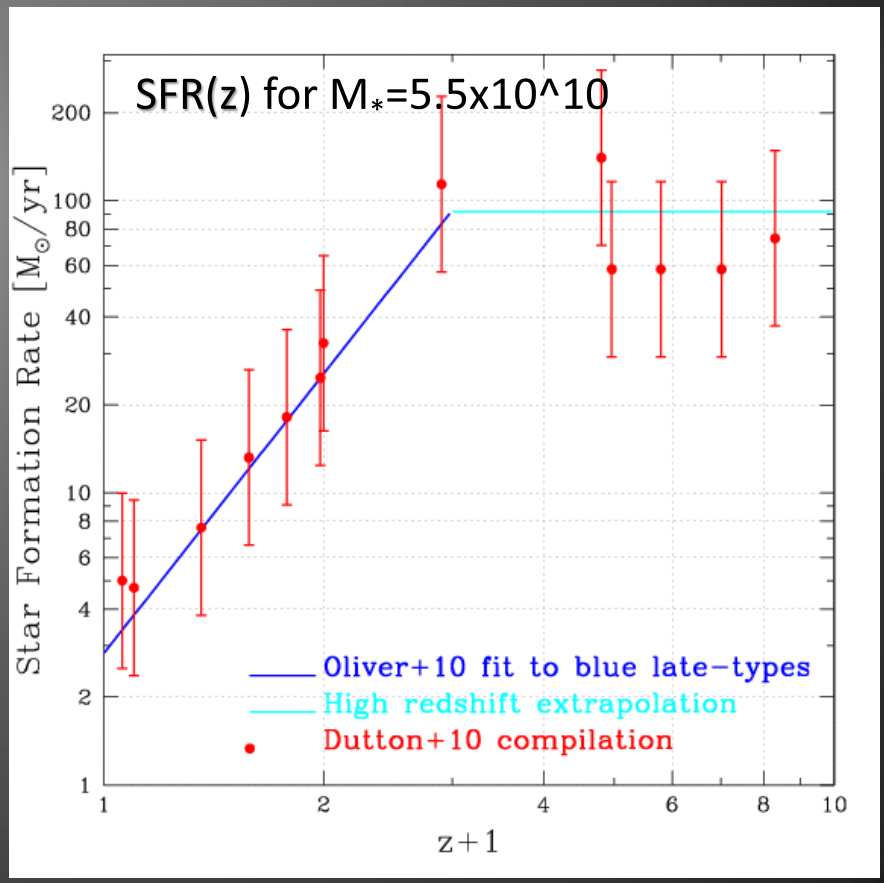
Importance of Gas Reprocessing to Star Formation Rate Budget

Un-Integrating Star Formation

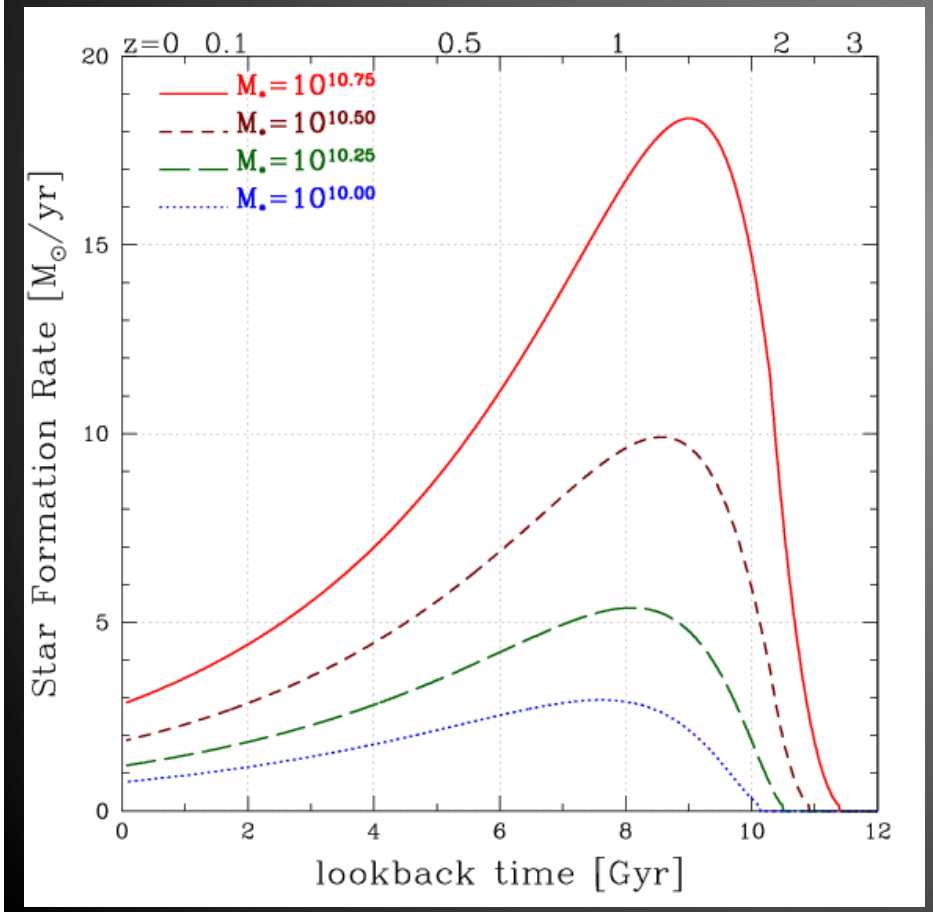
- Step back in time, removing stellar mass according to average star formation rate.



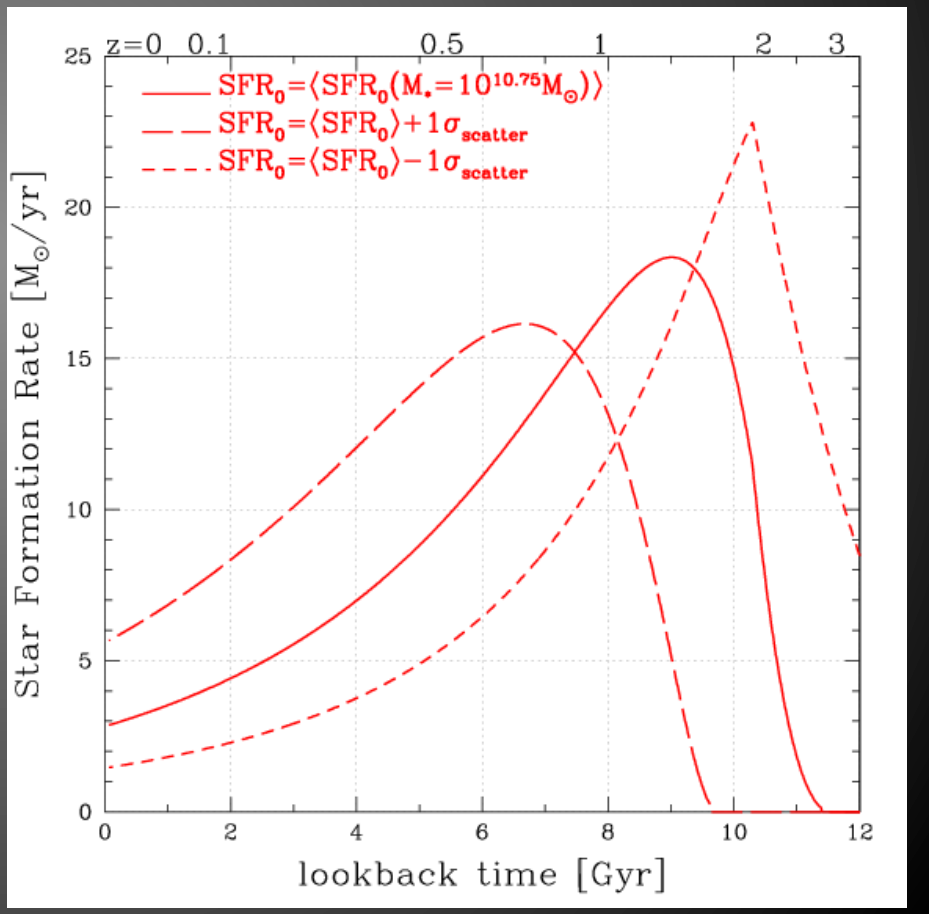


Star Formation Histories

At the mean 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

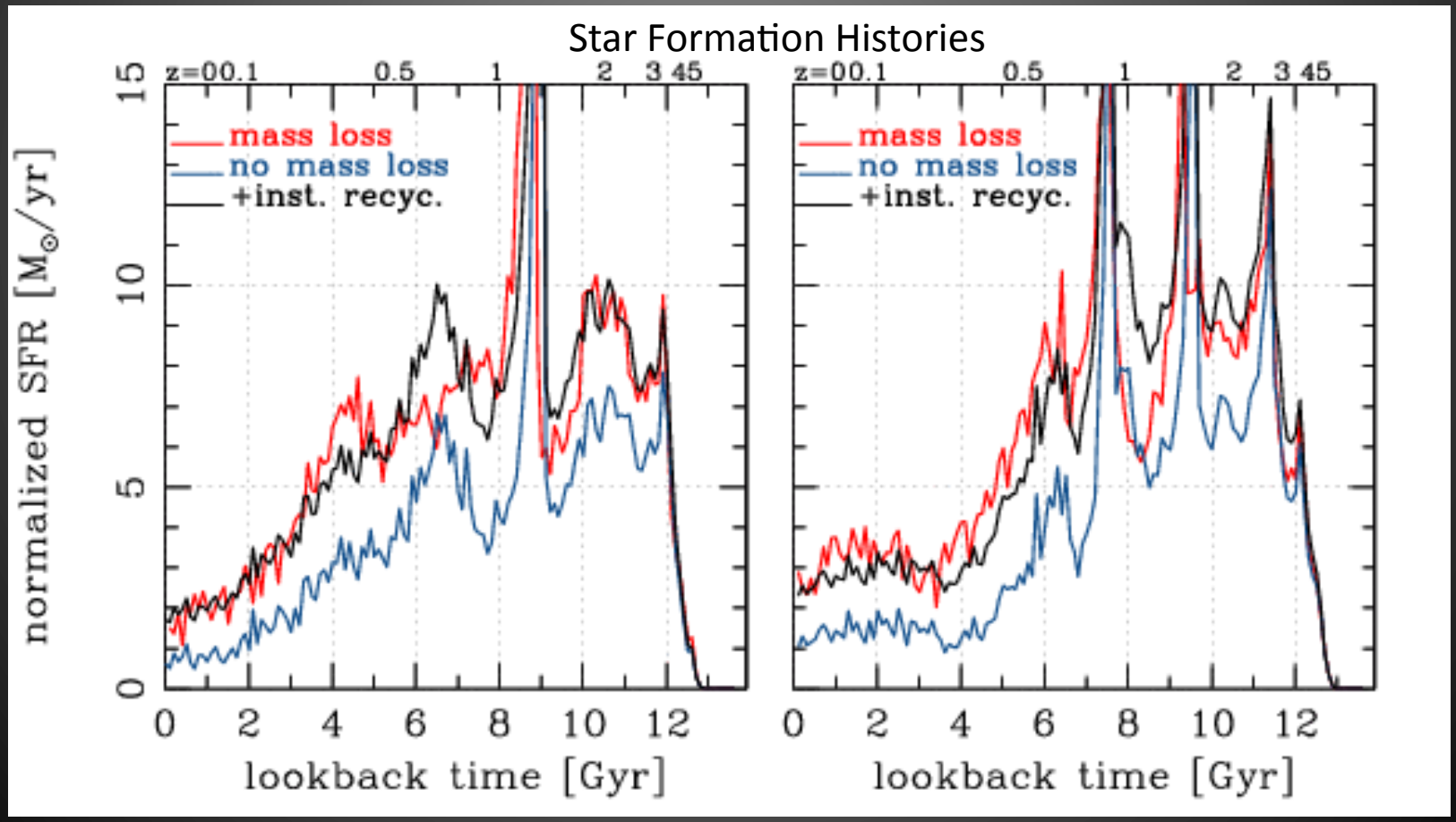
Method

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

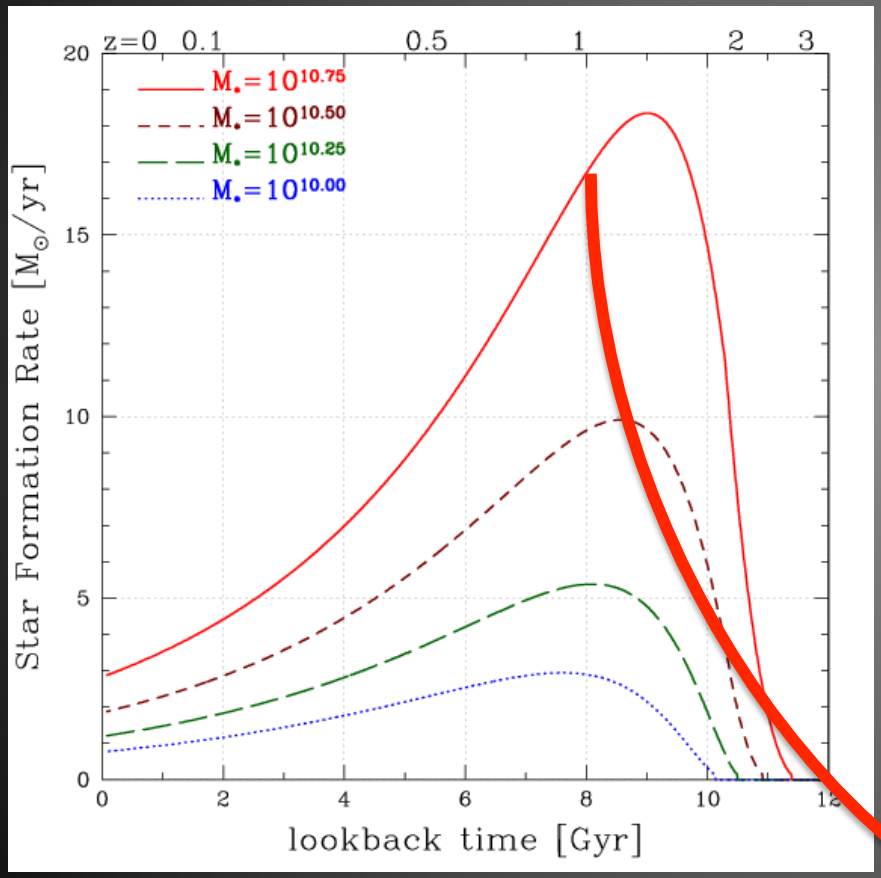
Gas Reprocessing Model

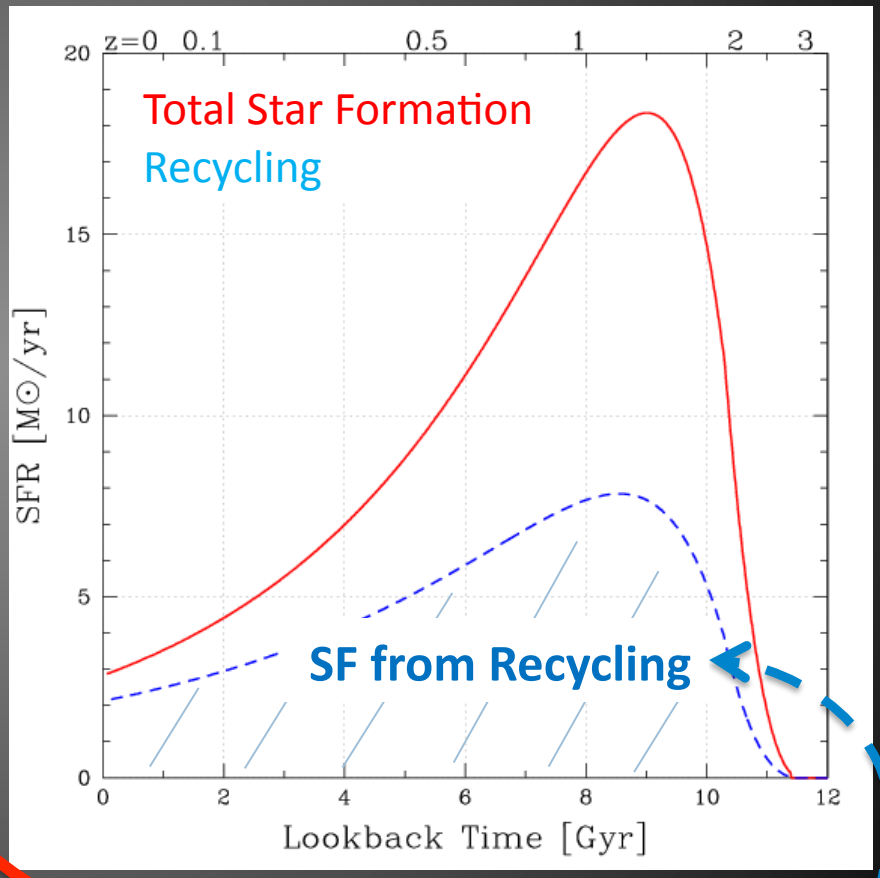
- Simulated Milky Way Mass Halos demonstrate that the instant recycling of lost stellar material accounts for additional star formation.



Star Formation Histories

Reprocessing Contribution





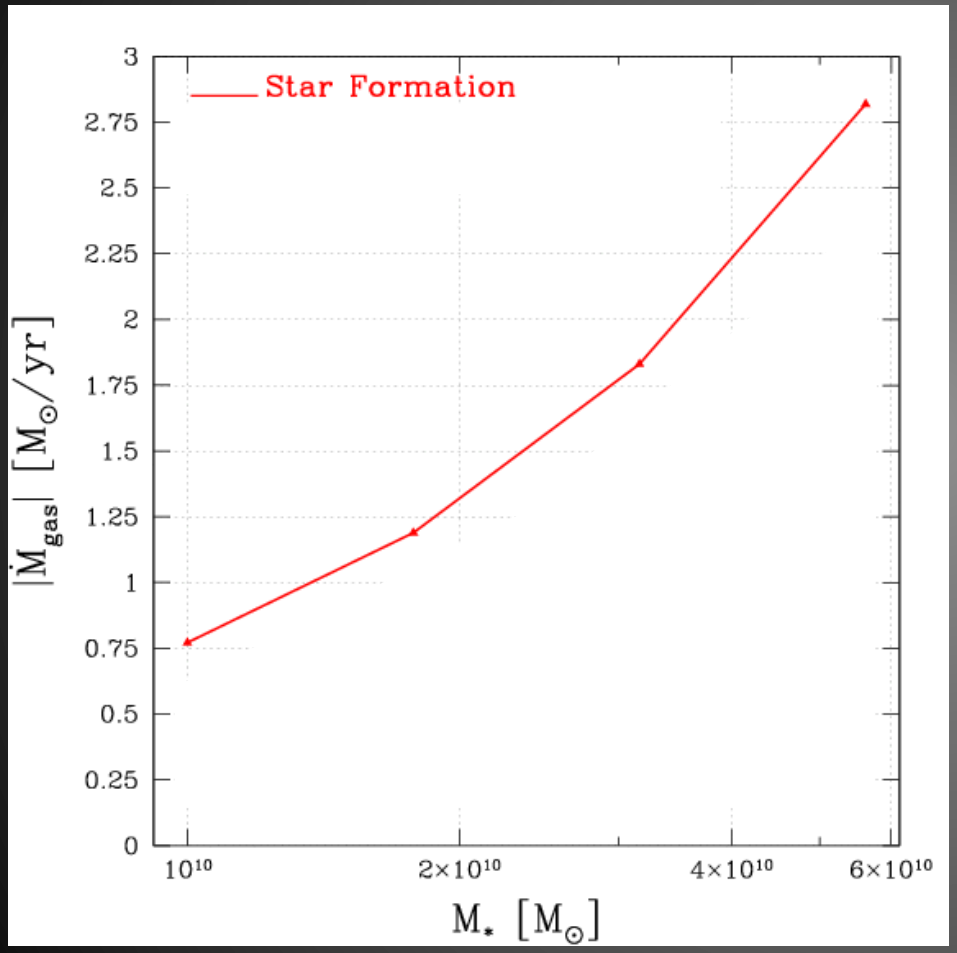
Recycling Model

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

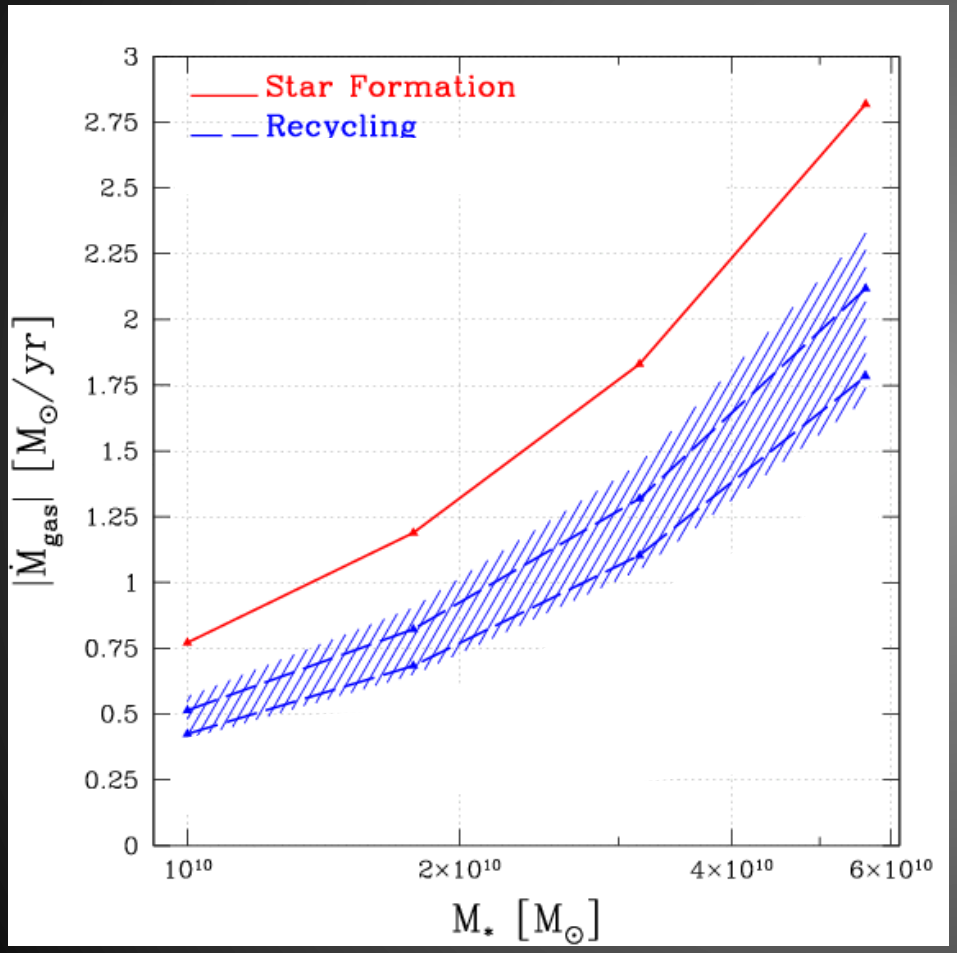
Importance of Gas Reprocessing to Star Formation Rate Budget

z=0 Reprocessing Predictions



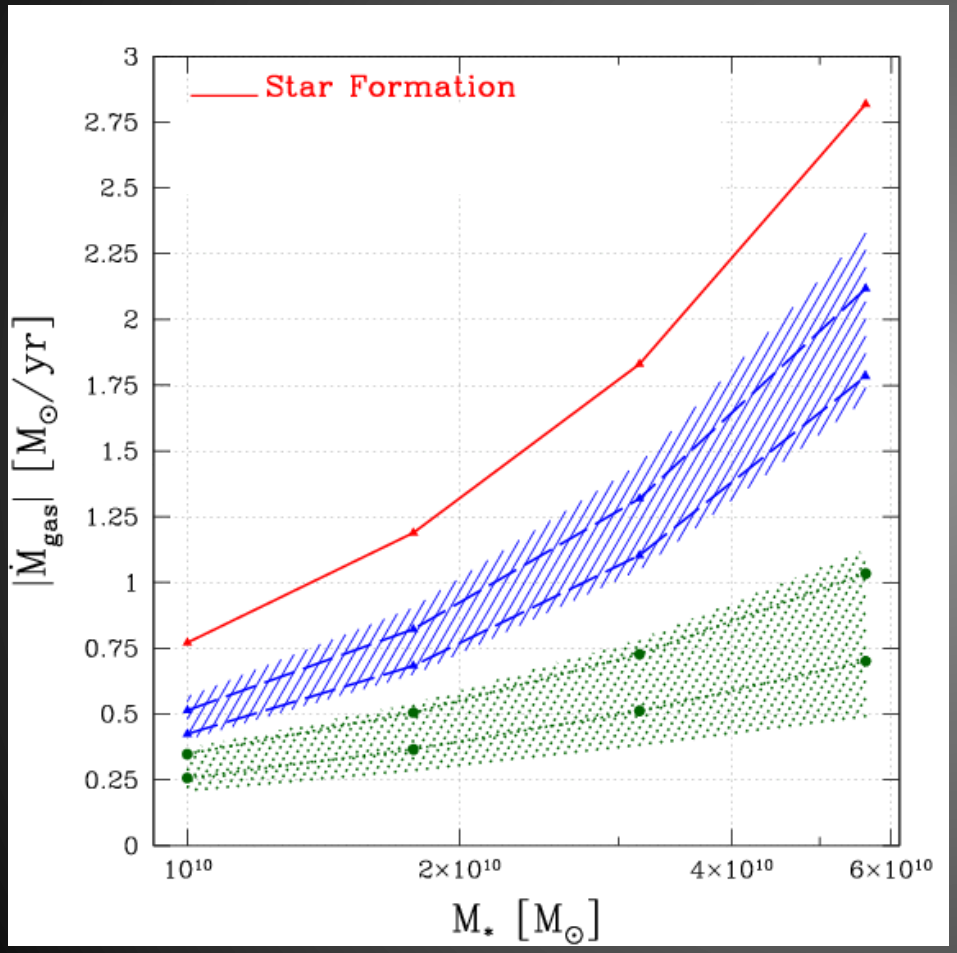
- Average star formation rate as a function of M_*.

z=0 Reprocessing Predictions



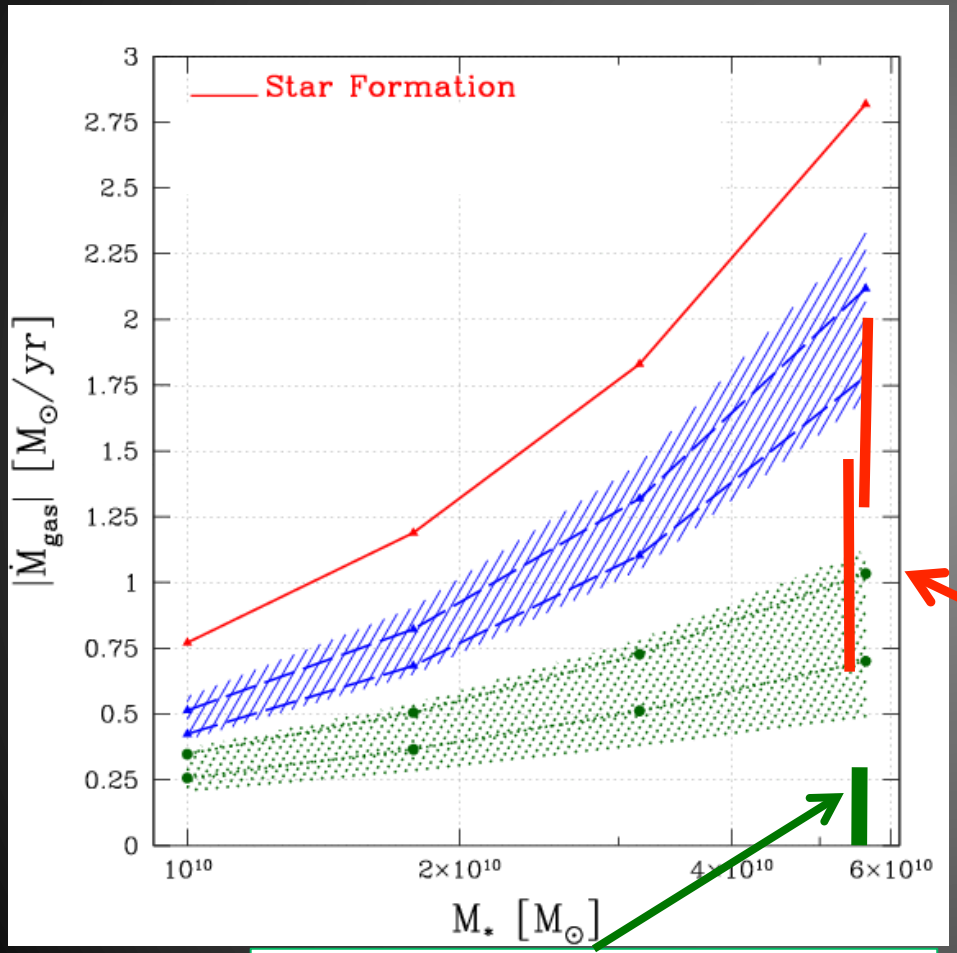
- Average star formation rate as a function of M_*.
- Average recycling rate for galaxies with average star formation rate as a function of M_* including modeling uncertainty

z=0 Reprocessing Predictions



- Average star formation rate as a function of M_*.
- Average recycling rate for galaxies with average star formation rate as a function of M_* including modeling uncertainty
- Average accretion rate needed to replenish the gas disk (from HI infall?)

z=0 Reprocessing Predictions

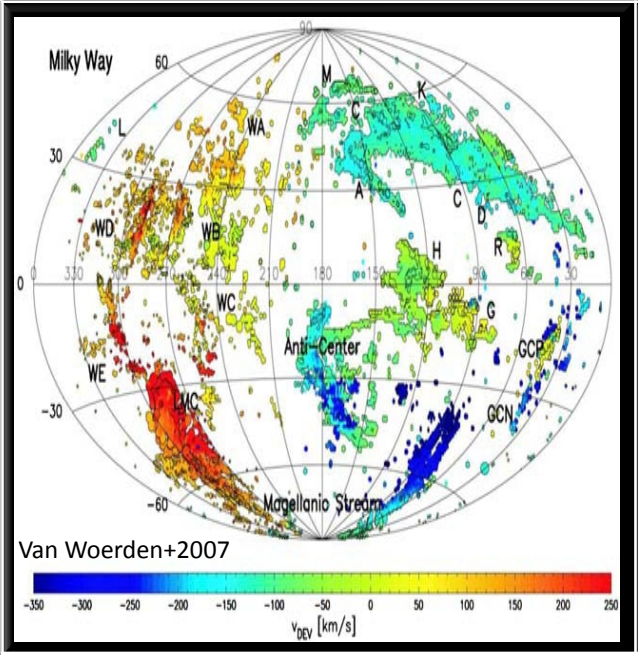


- Average star formation rate as a function of M_*.
- Average recycling rate for galaxies with average star formation rate as a function of M_* including modeling uncertainty
- Average accretion rate needed to replenish the gas disk (from HI infall?)

Milky Way infall needed at observed SFR

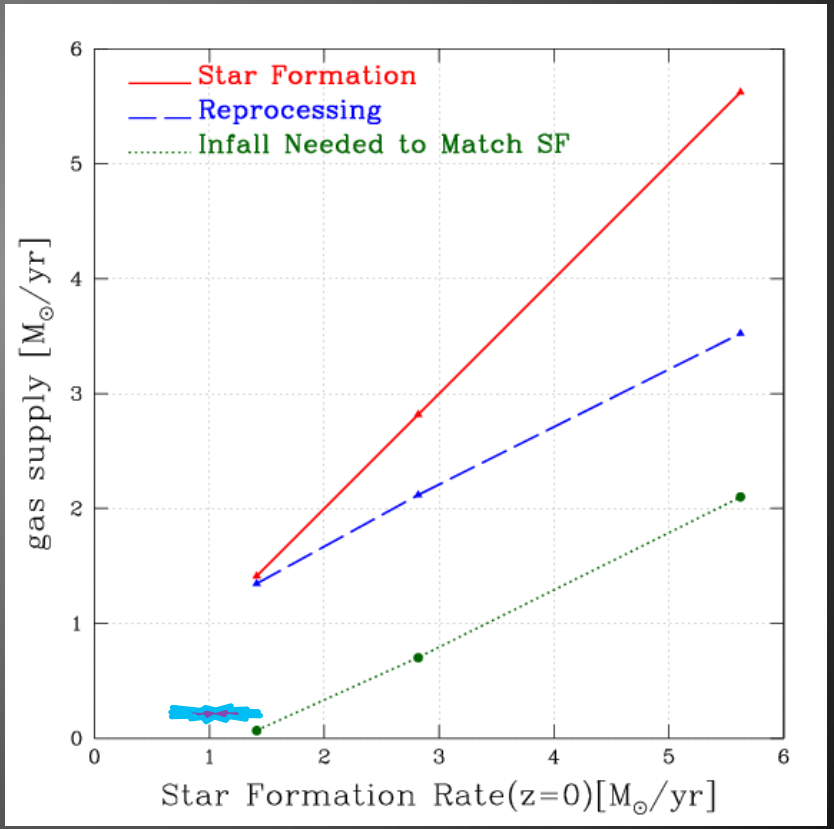
Most recent Milky Way star formation rate measurements. (Murray & Rahman 2010,Robitaille & Whitney 2010)

Gas Budget *with* Recycling

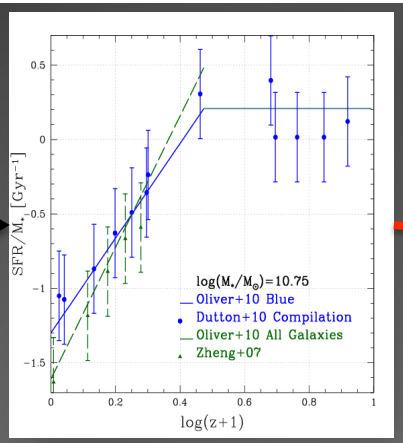


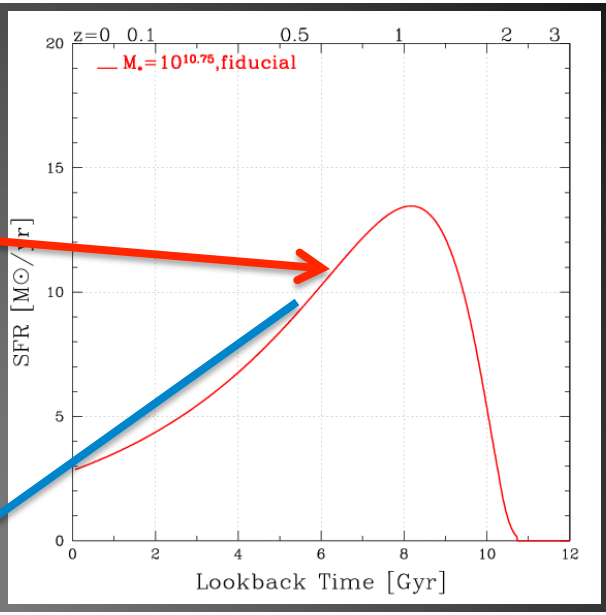
Recycled≈1.3$M_o yr^{-1}$	**Recycled≈2.4$M_o yr^{-1}$**	**Recycled≈0.8$M_o yr^{-1}$**
HI Infall≈0.1-.25$M_o yr^{-1}$	**HI Infall ≈0.1-0.2$M_o yr^{-1}$**	**HI Infall≈0.1-0.2$M_o yr^{-1}$**
SFR≈1.5$M_o yr^{-1}$	**SFR≈3.8$M_o yr^{-1}$**	**SFR≈1$M_o yr^{-1}$**
Deficit≈0	**Deficit≈1.4$M_o yr^{-1}$**	**Deficit≈0**

Average return rate for a Milky Way Mass galaxy with varying present day star formation rates

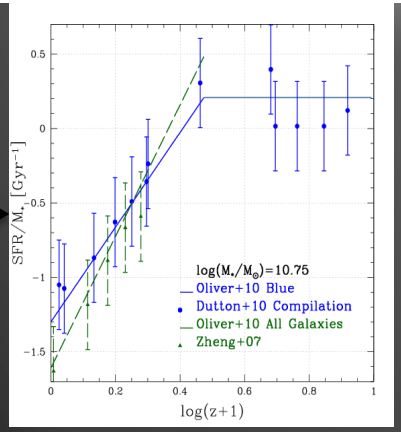


$M^* = M_{*0}$ -SFR(M^*,z) → SF History ^{0}

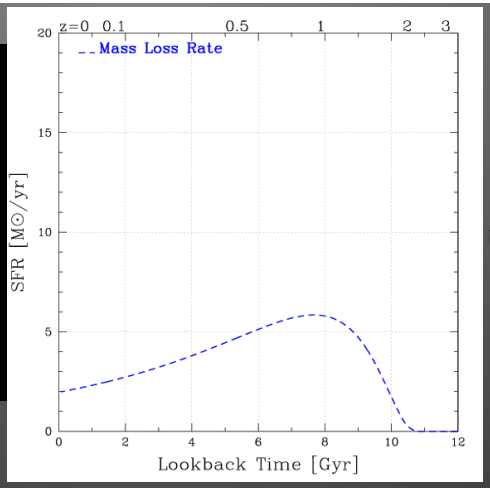


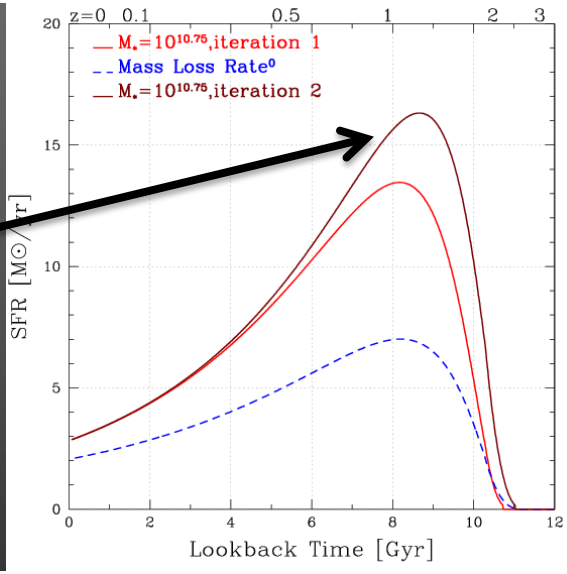


$M^* = M_{*0}$ - SFR(M^*,z) + Mass Loss(z)^0 → SF History ^{1}

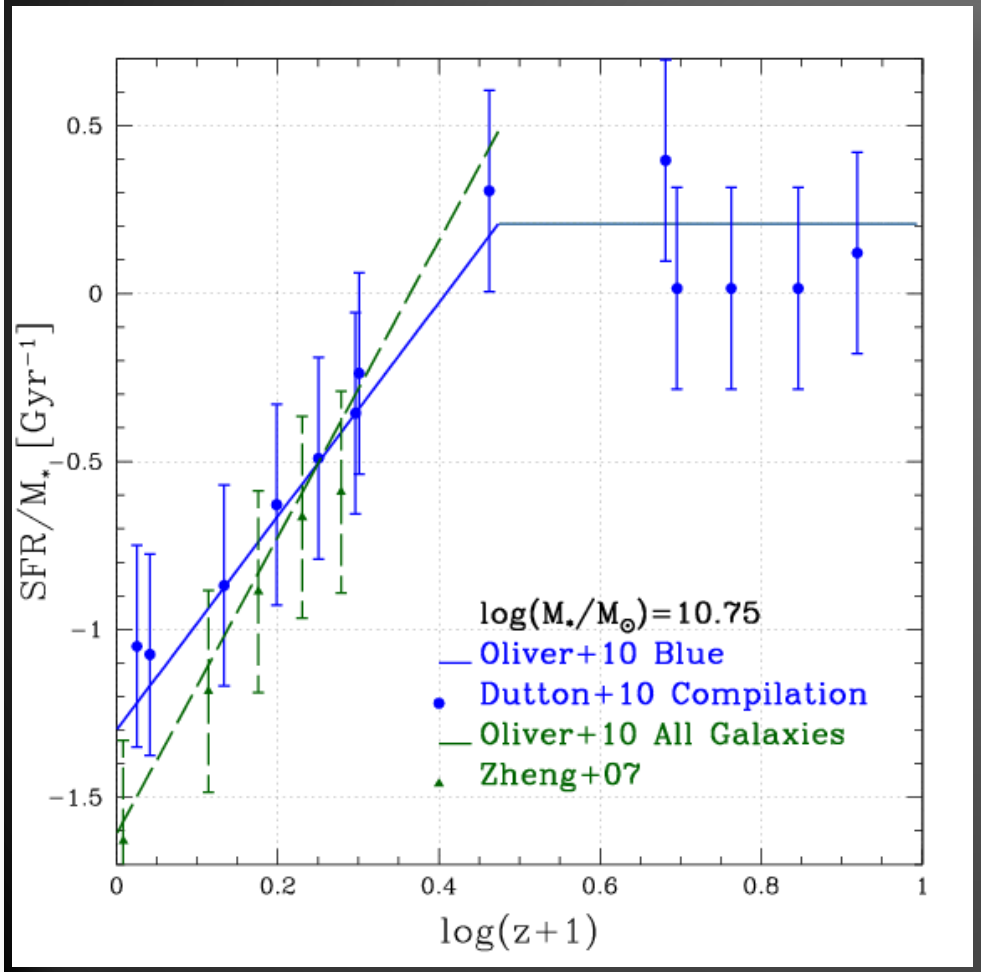


Mass Loss Rate

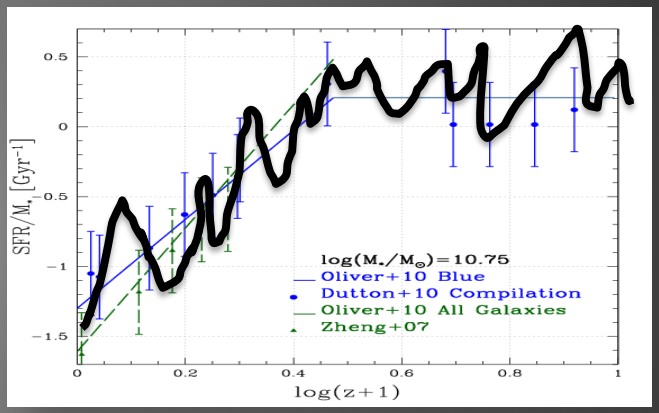




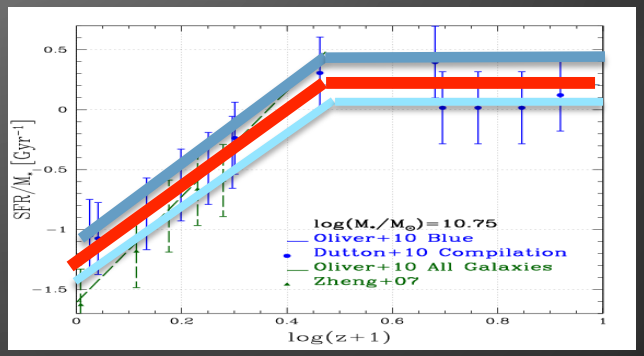
Results Robust to Scatter?



- Stochastic scatter



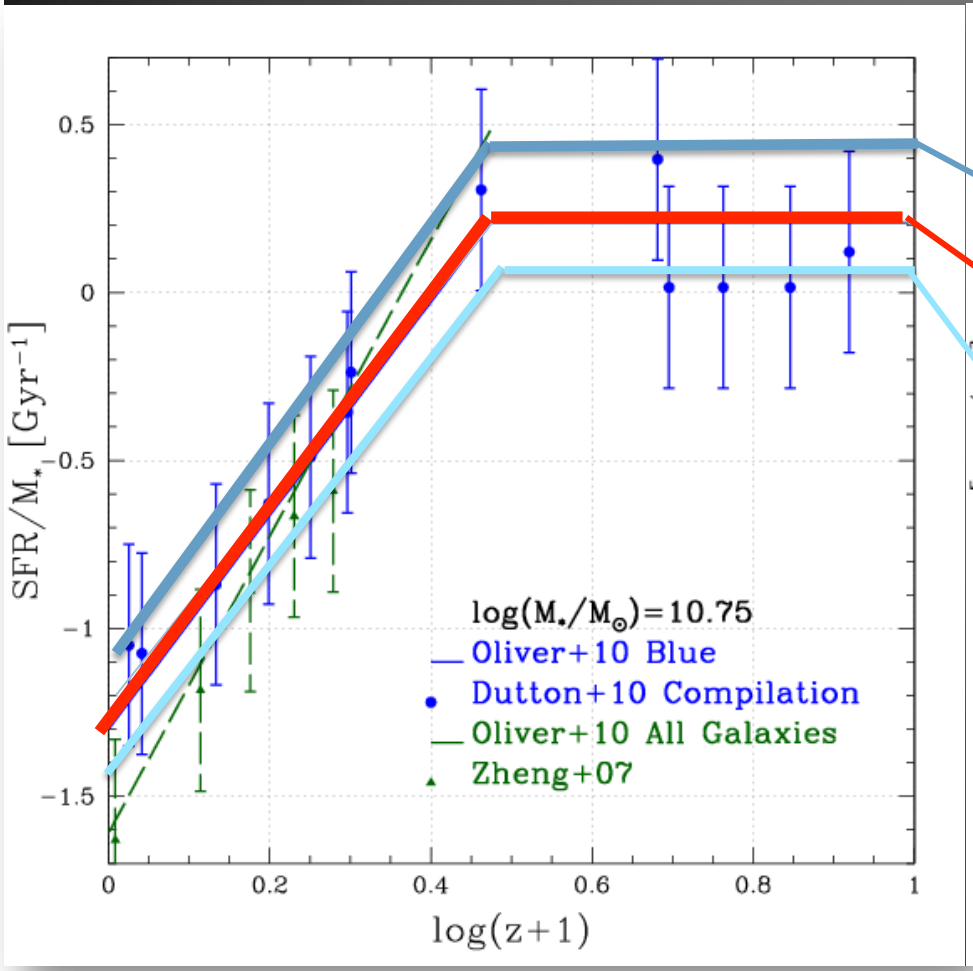
- Scatter in scaling

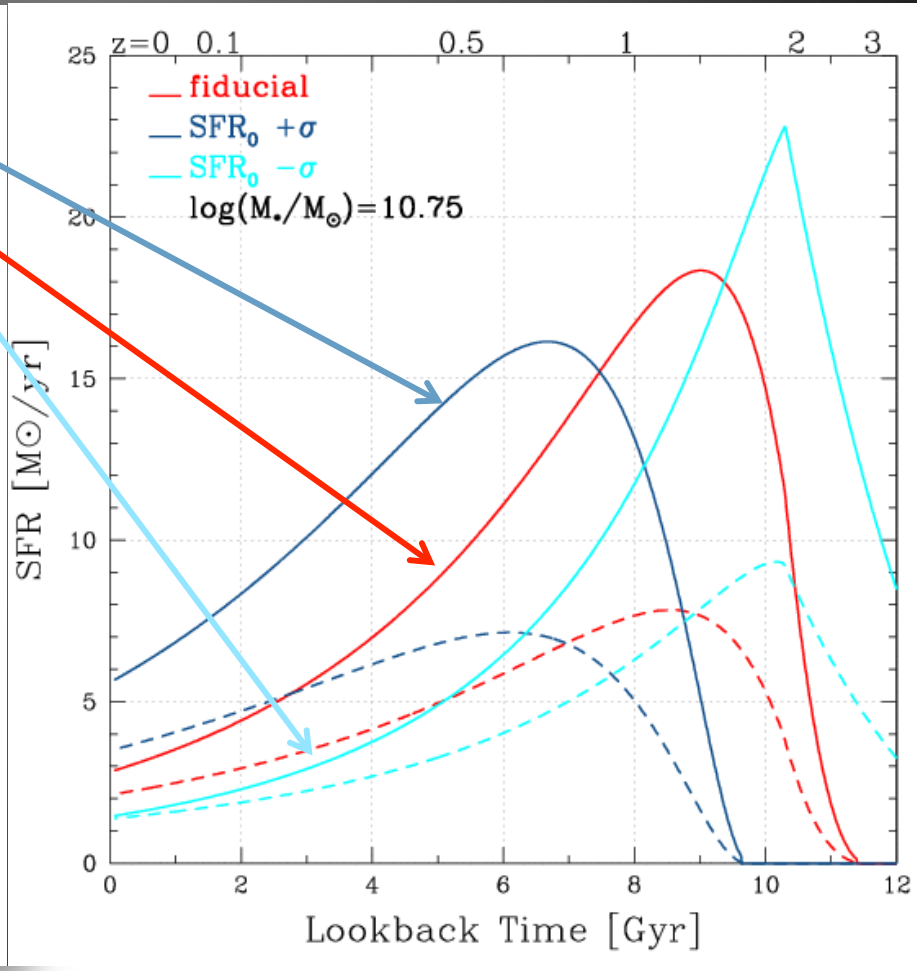


Systematic Scatter

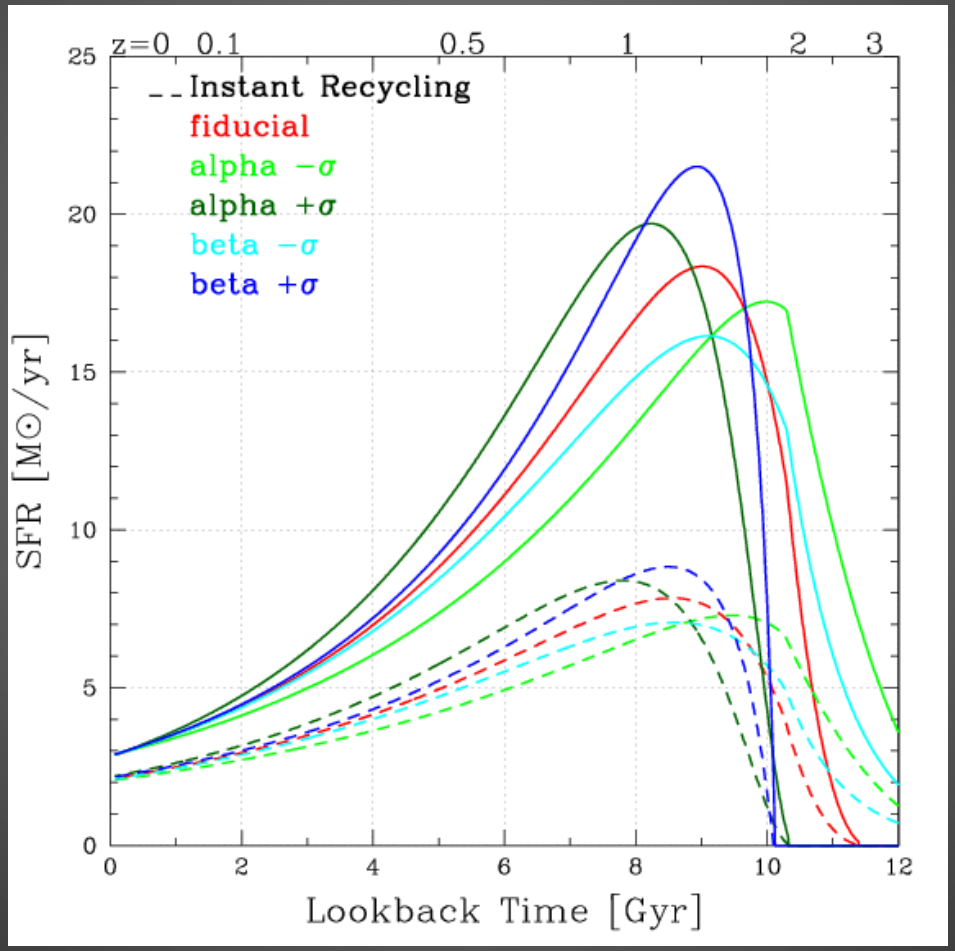
SFR(z,M*) Scaling

SFR+ Reprocessing





SFR Slope Uncertainties



Mass Loss Model