THE EVOLUTION OF STAR-FORMING GALAXIES OVER COSMIC TIME

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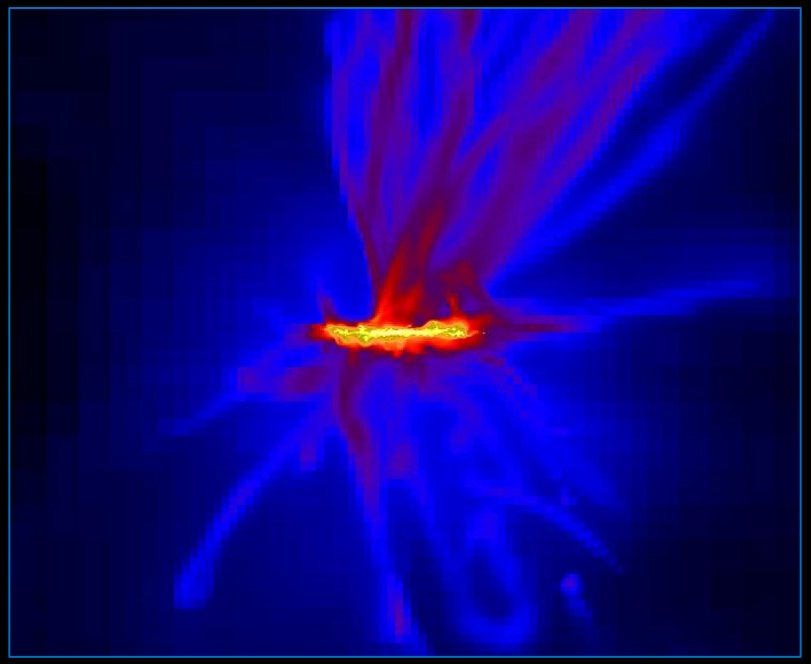
Galaxy Evolution in a Nutshell

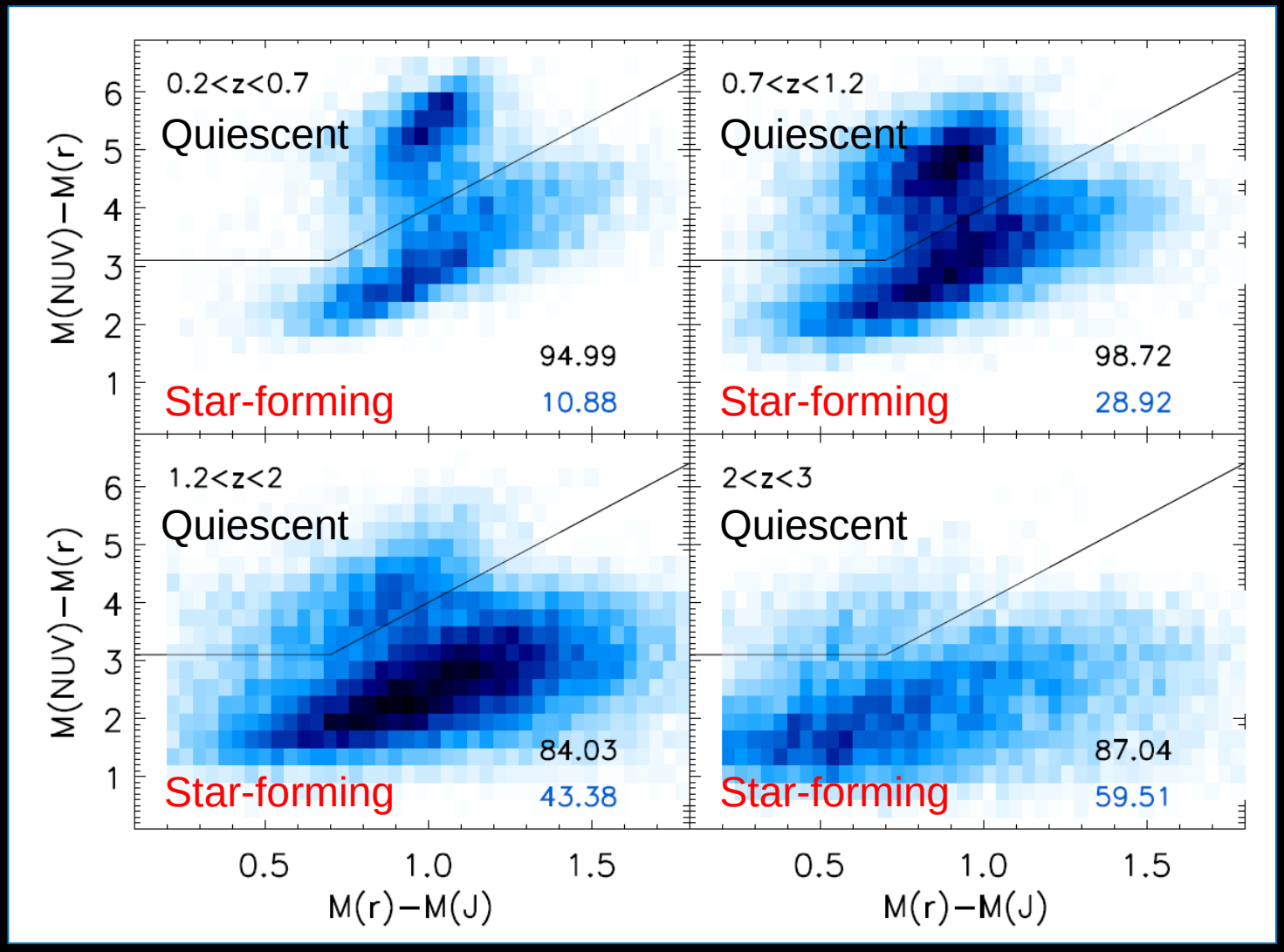
- Two evolutionary extremes:
  - Stochastic process (e.g. major/minor merger-dominated)
    - Every galaxy is unique.
  - Deterministic process (e.g. quasi-continuous gas accretion)
    - Every galaxy is the same.

http://www.spacetelescope.org/images/heic0615a/



http://www.stsci.edu/~inr/thisweek1/2010/thisweek228.html

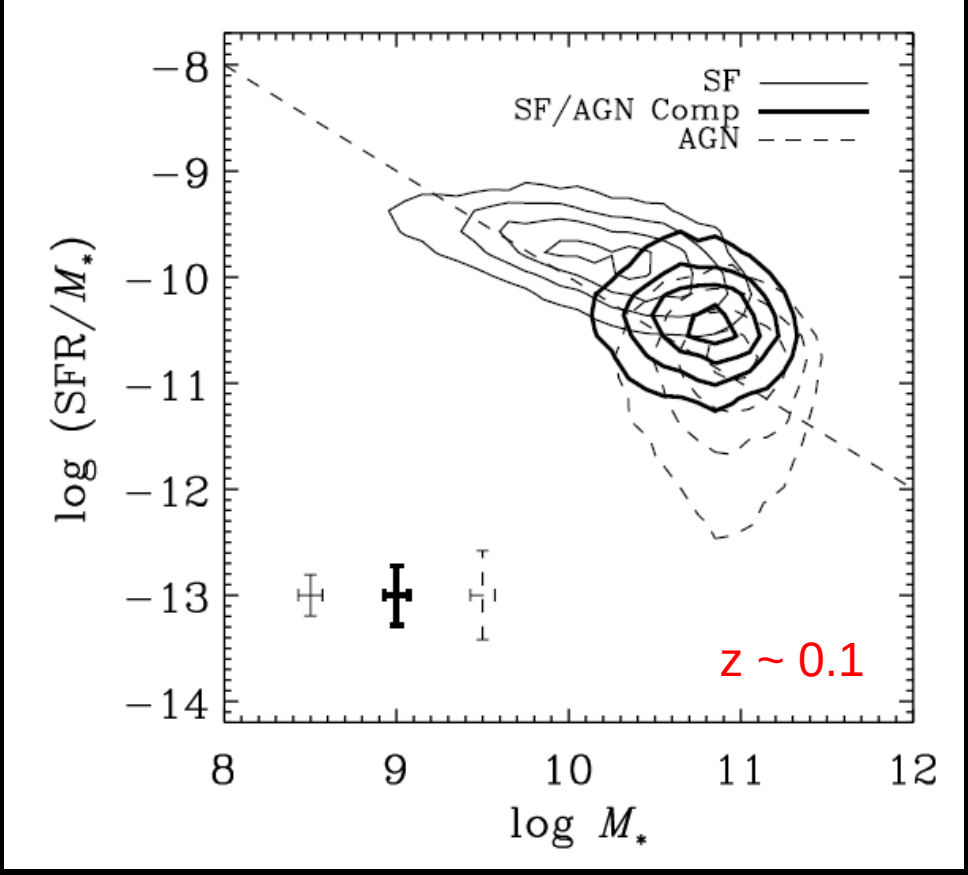
What are Star-Forming Galaxies?



Taken from Ilbert et al. (2013).

The Star-forming “Main Sequence”

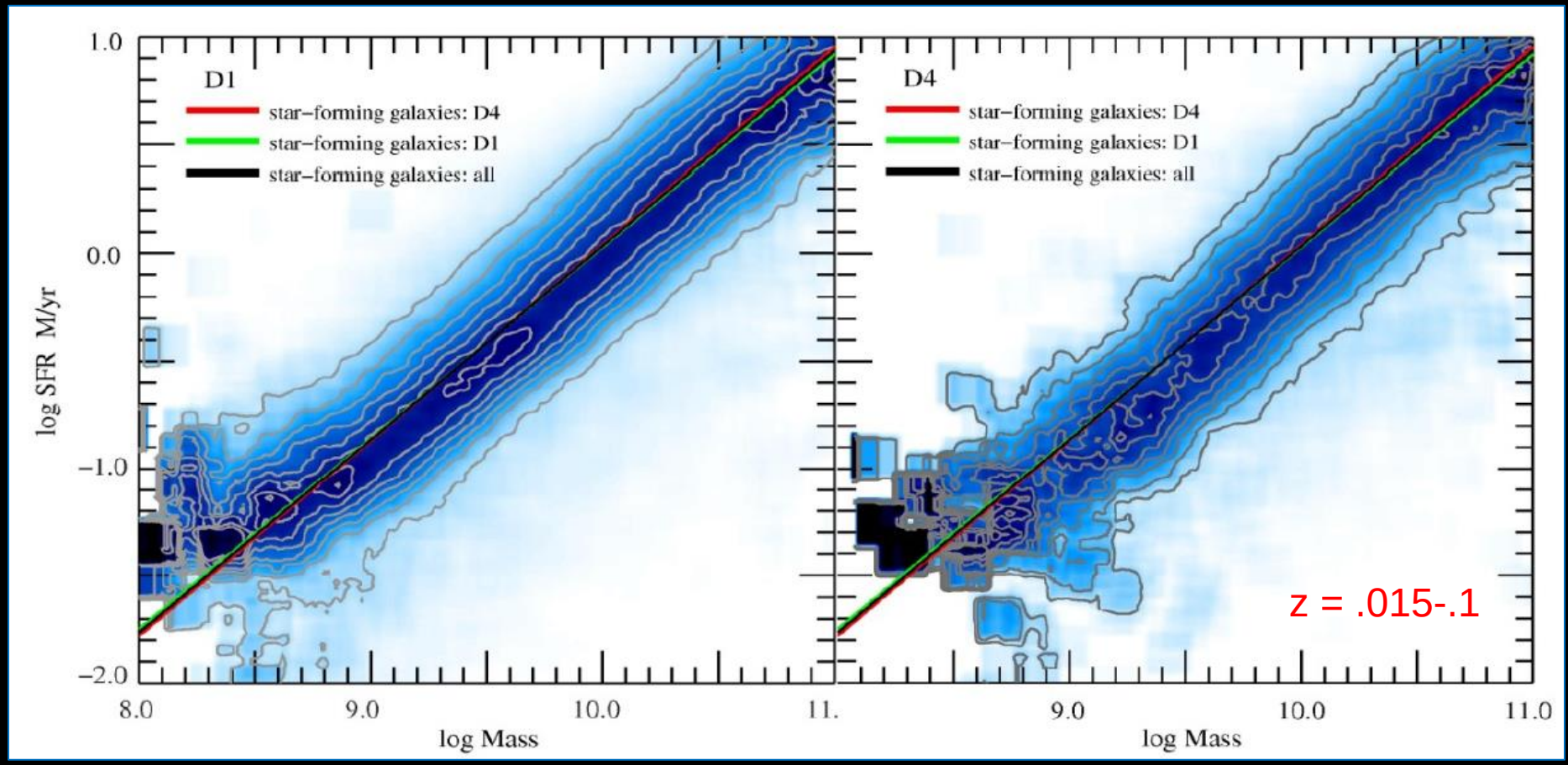
- Strong correlation (~.25-.3 dex) between M and SFR when AGN are removed.



Taken from Salim et al. (2007).

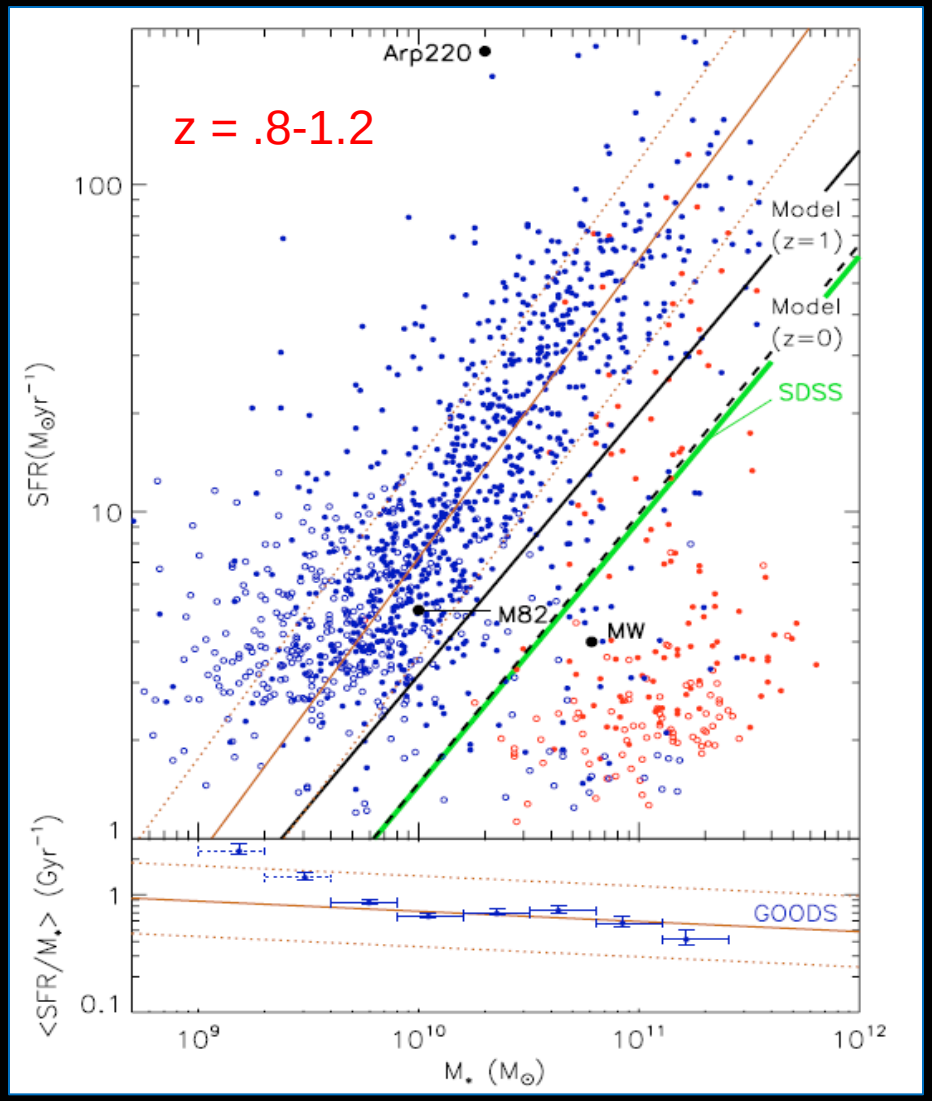
The Star-forming "Main Sequence"

- MS present regardless of environment.



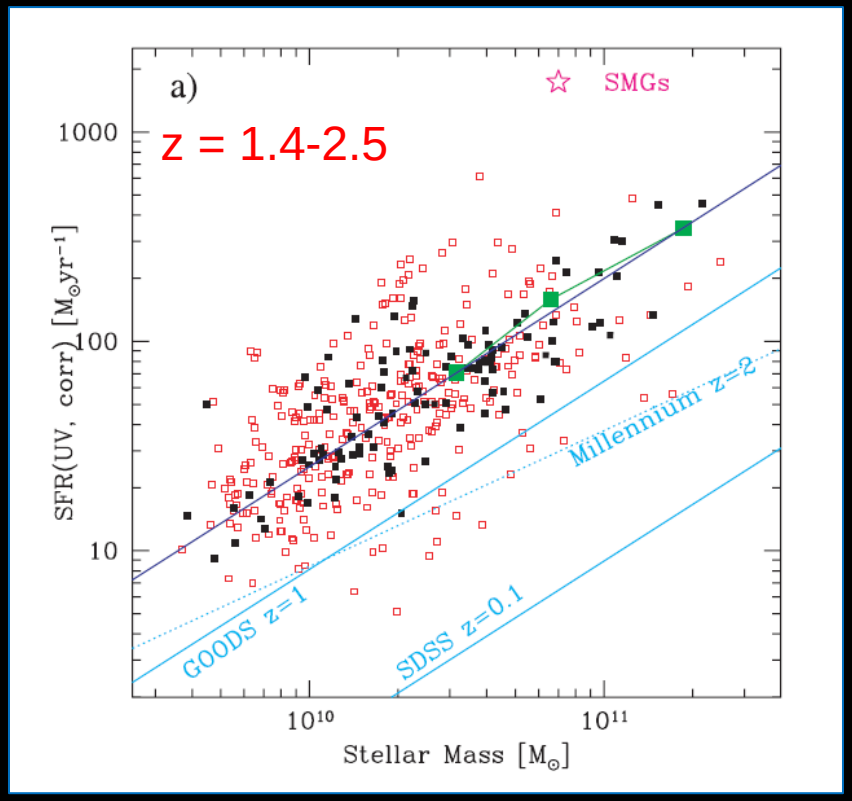
Taken from Peng et al. (2010).

The Star-forming "Main Sequence"



Taken from Elbaz et al. (2007).

- Seen across a wide range of redshifts.



Taken from Daddi et al. (2007).

Implications of the “Main Sequence”

- Evolution of the MS over time gives insight into the galaxy-SFR relation.
- Tight relationship suggests similar galaxy evolutionary tracks.
- Hints at underlying baryonic physics surrounding galaxy formation.
- Possible ties to AGN activity, evolution, quenching.

Questions We Want to Answer

- How does the MS evolve over time?
- Are the current fits to the MS relationship correct?
- How does selection effects, SFR indicators affect our conclusions?
- Is there a relationship between MS galaxies and AGN?

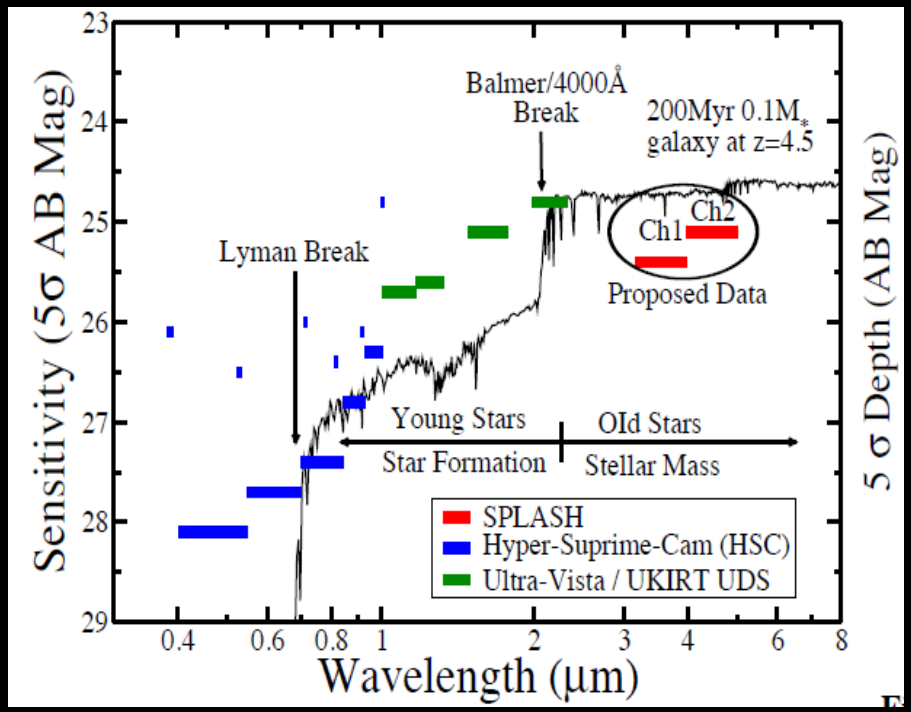
Questions We Want to Answer

- Is the MS present at even earlier times?
- Are the current fits to the MS relationship correct?
- To what extent do SFR indicators and selection effects influence the observed MS?
- How does the MS evolve over time?
- Is there a relationship between MS galaxies and AGN?

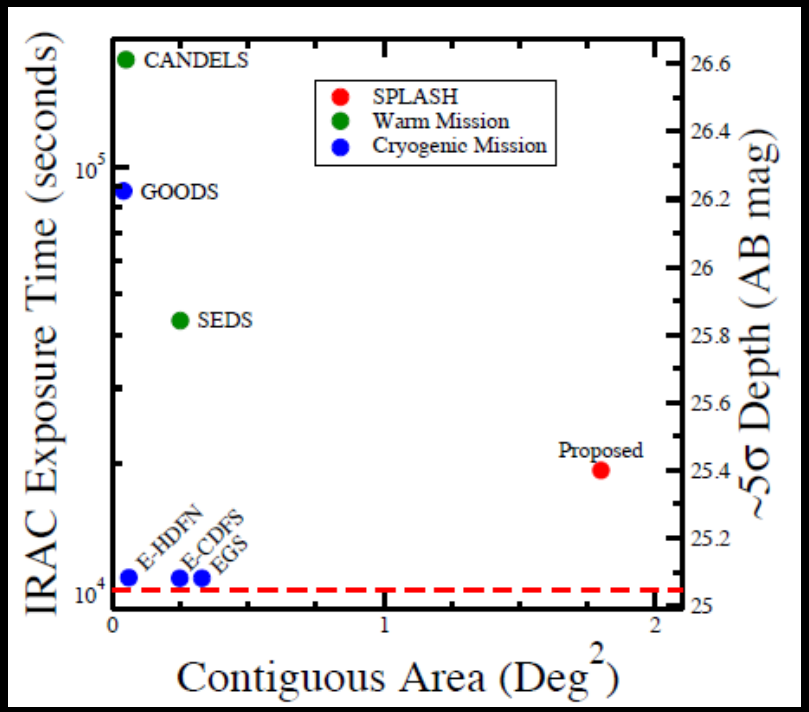
What is SPLASH?

- Spitzer Large Area Survery with Hyper-Suprime-Cam.

Extended Wavelength Coverage



Large Survey Area

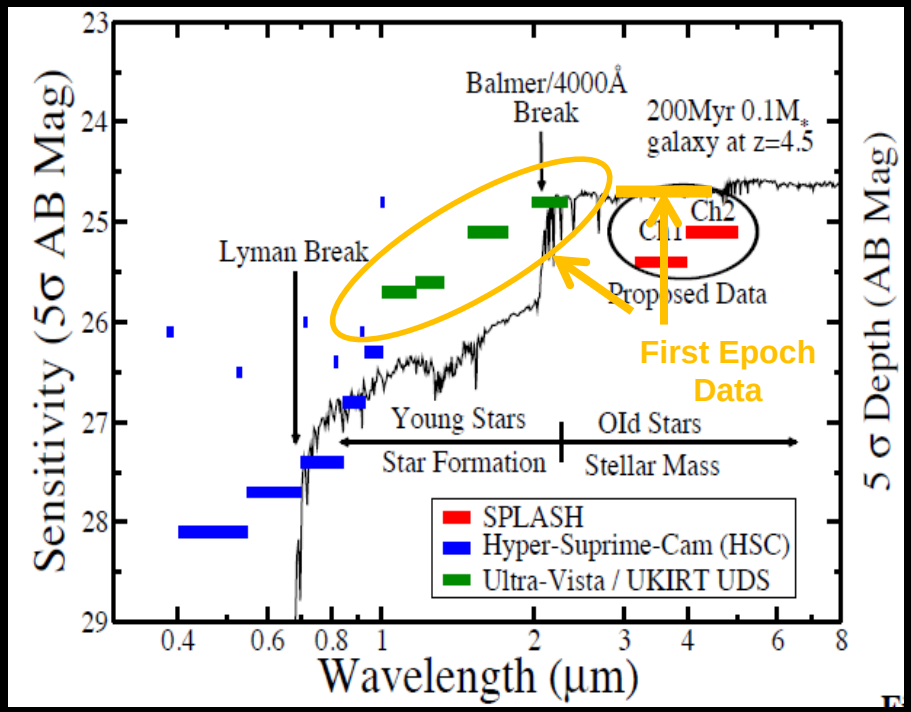


Taken from SPLASH Proposal (PI: Capak).

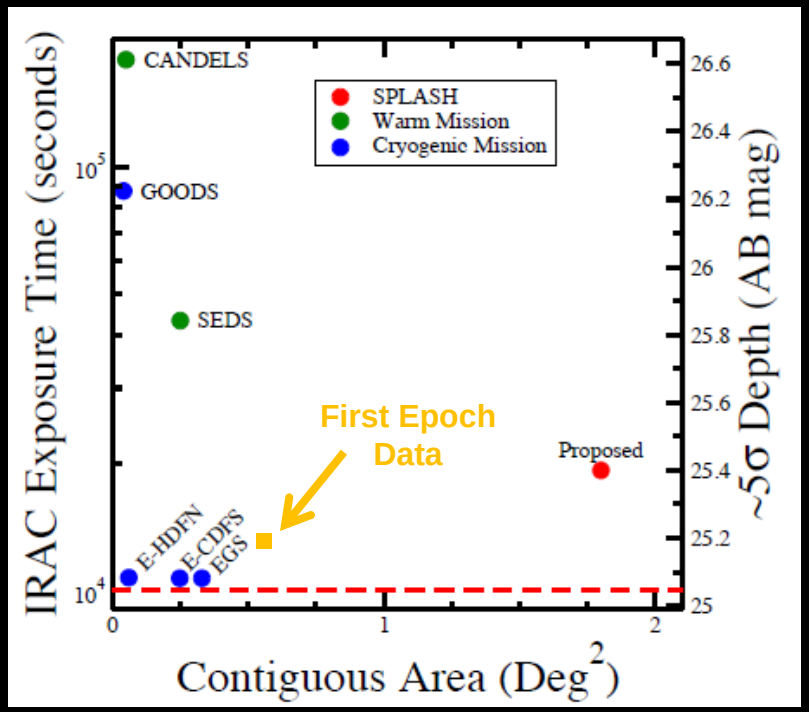
What is SPLASH?

- Spitzer Large Area Survery with Hyper-Suprime-Cam.

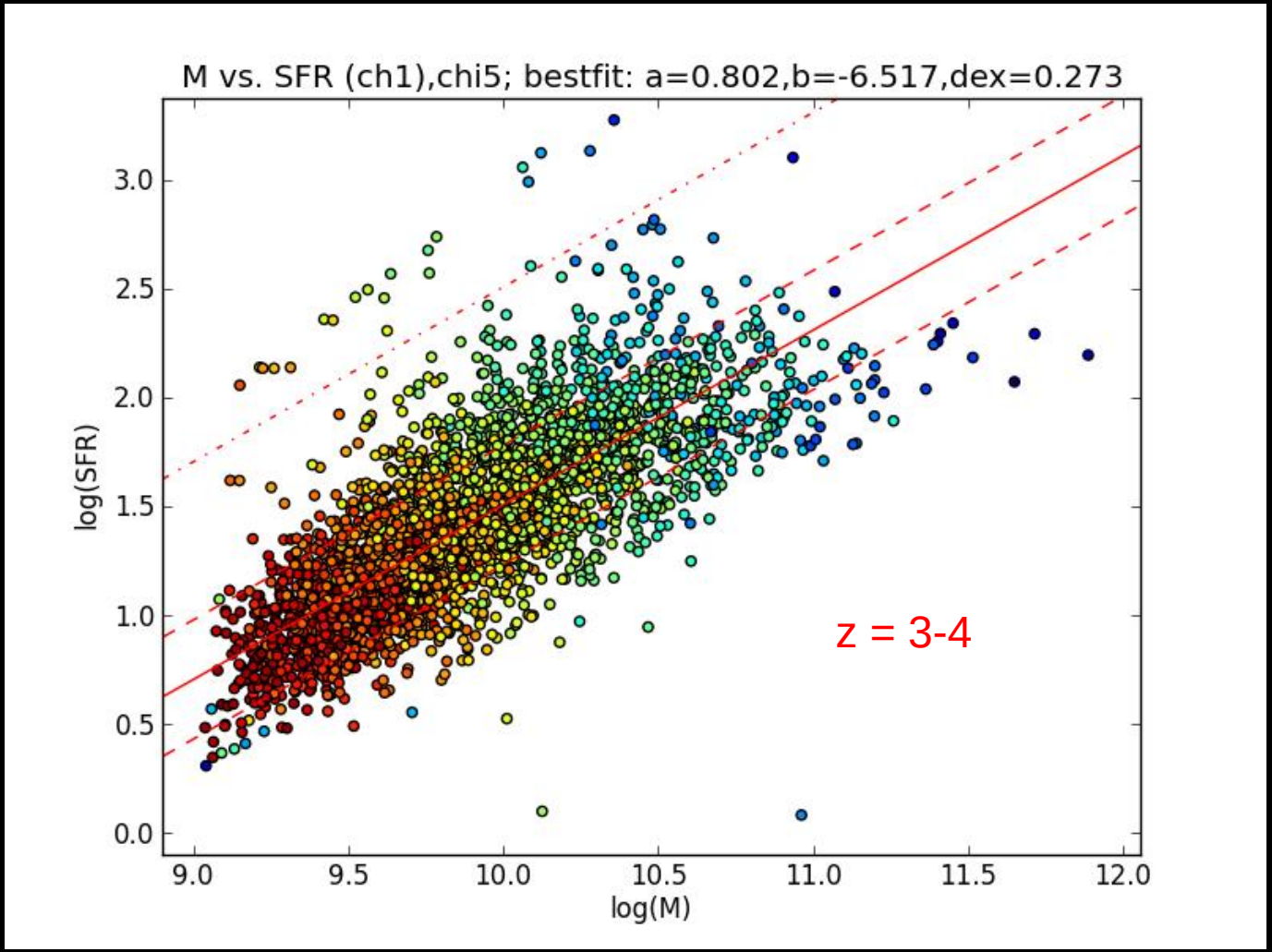
Extended Wavelength Coverage



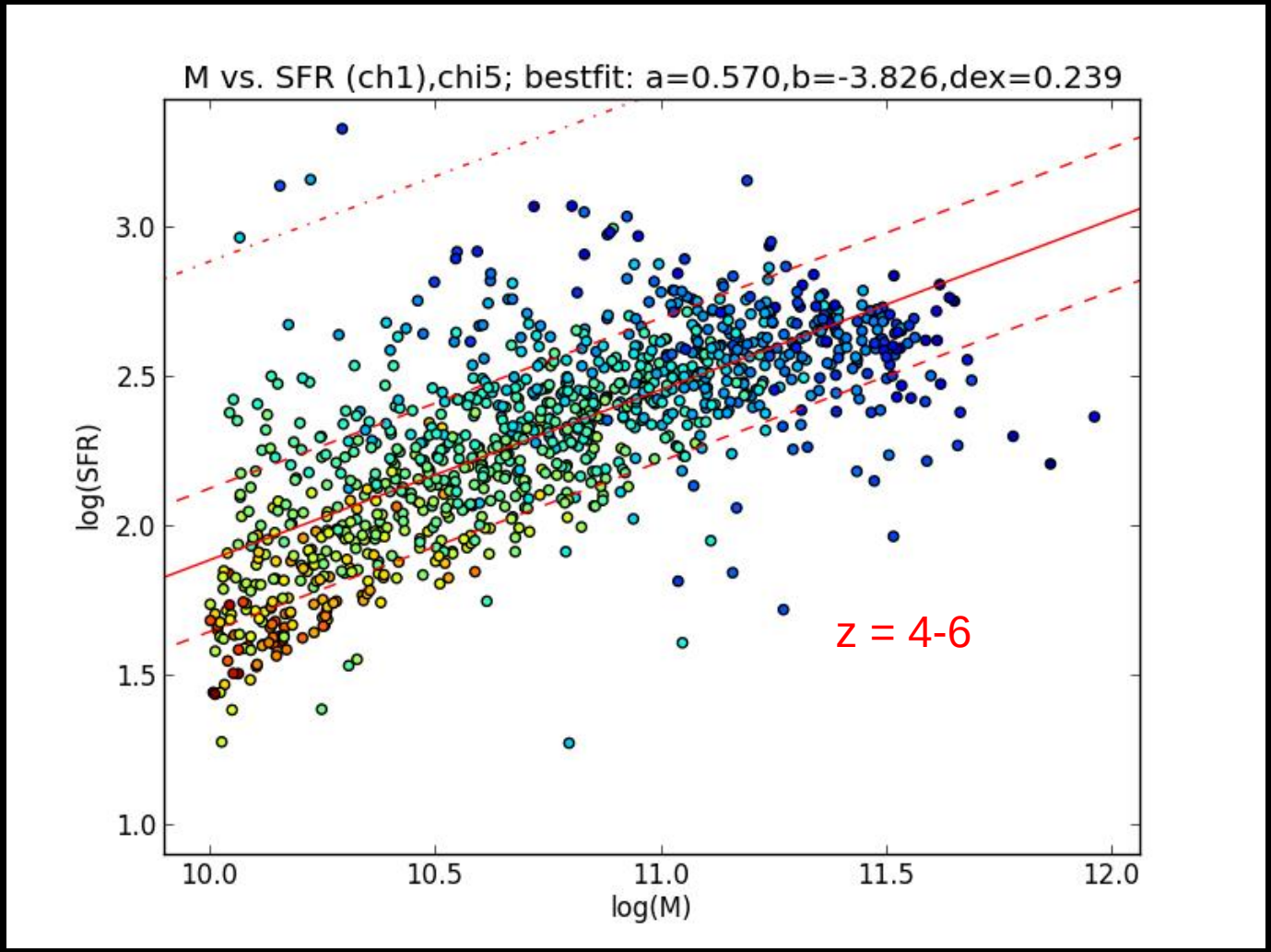
Large Survey Area



First Epoch SPLASH Data (z~3.5)



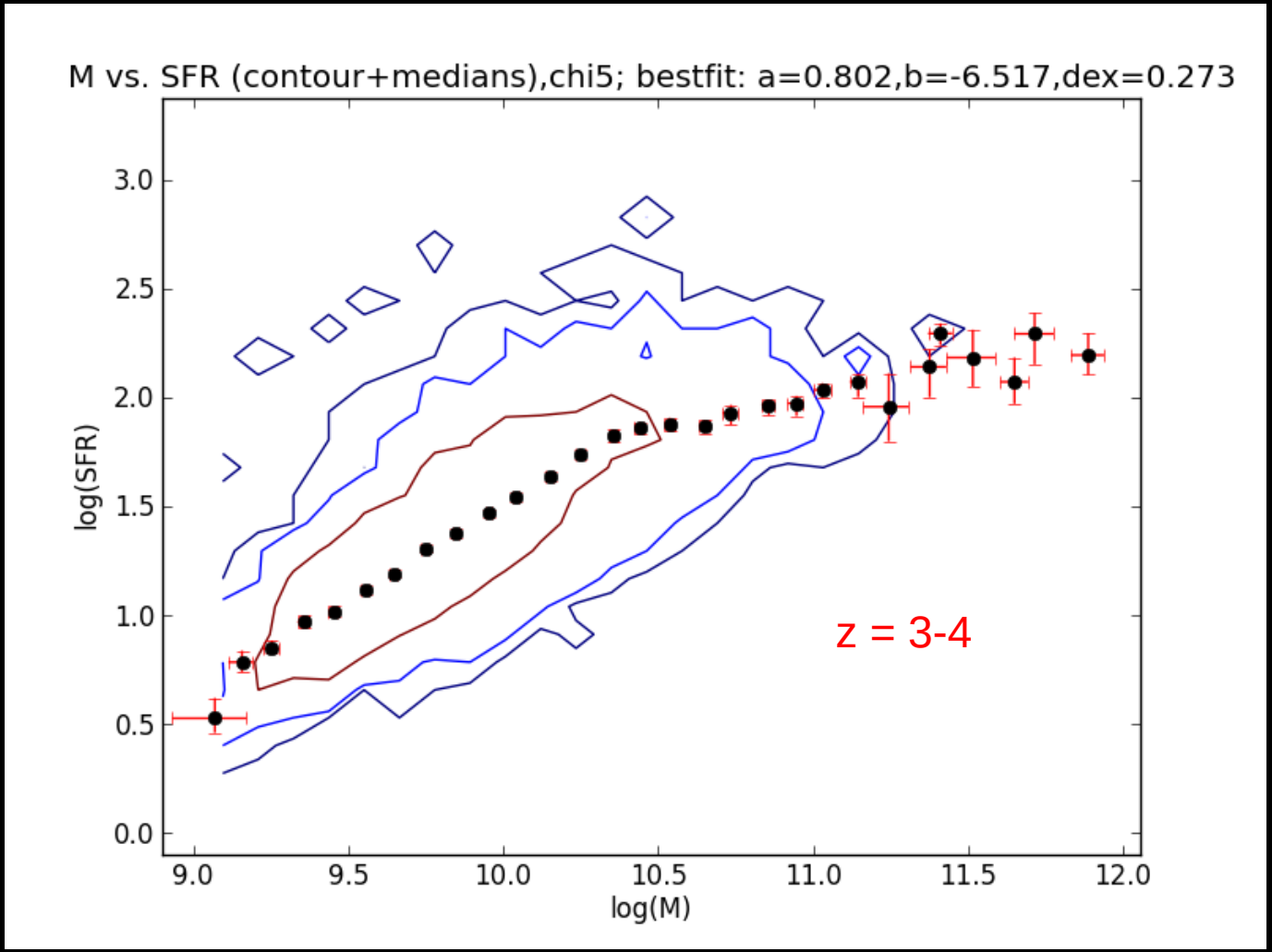
First Epoch SPLASH Data (z~5)



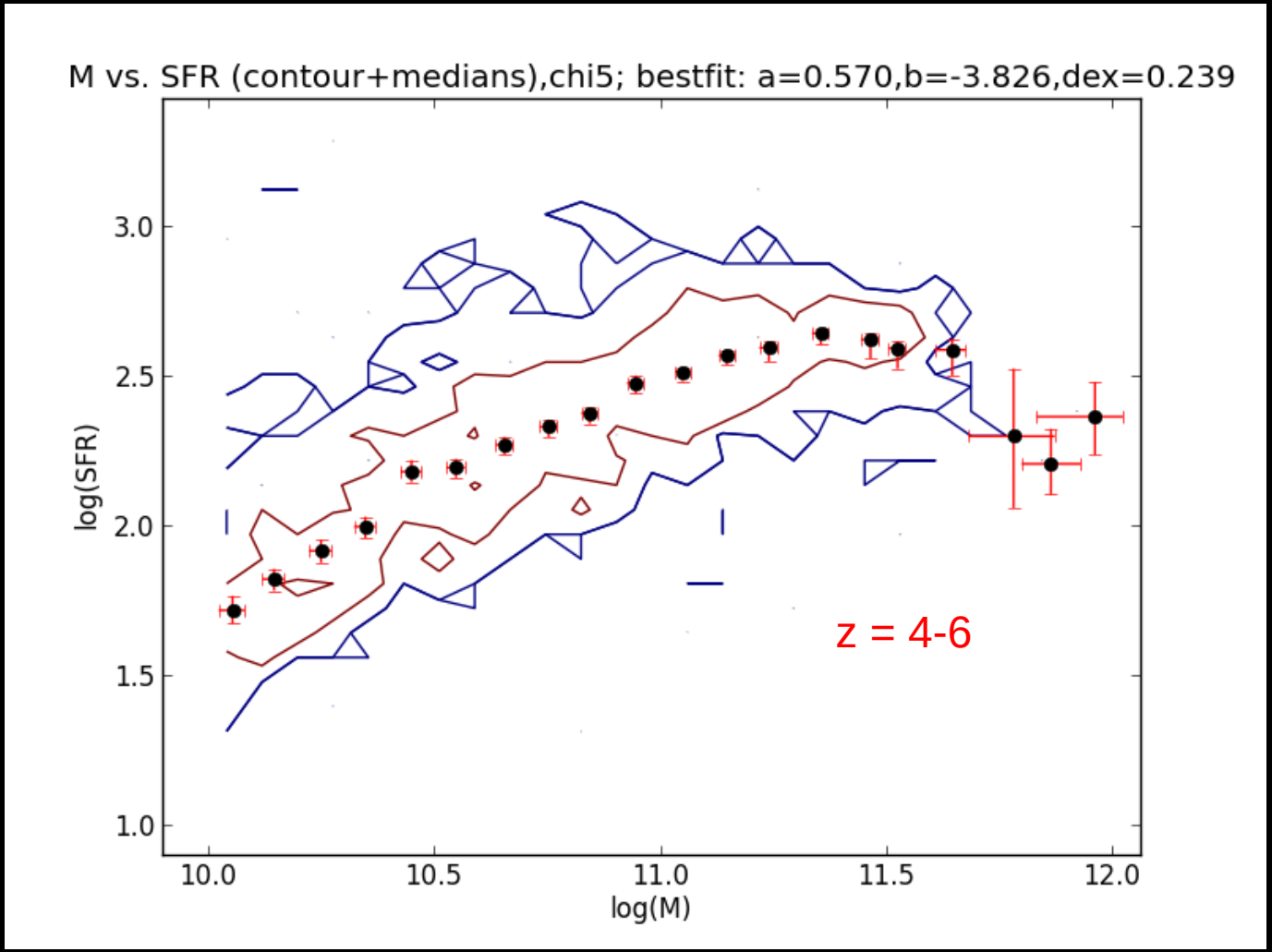
Questions We Want to Answer

- Is the MS present at even earlier times?
- Are the current fits to the MS relationship correct?
  - Is it really linear, or a more complex function?
- To what extent do SFR indicators and selection effects influence the observed MS?
- How does the MS evolve over time?
- Is there a relationship between MS galaxies and AGN?

MS “Turnoff” (z~3.5)



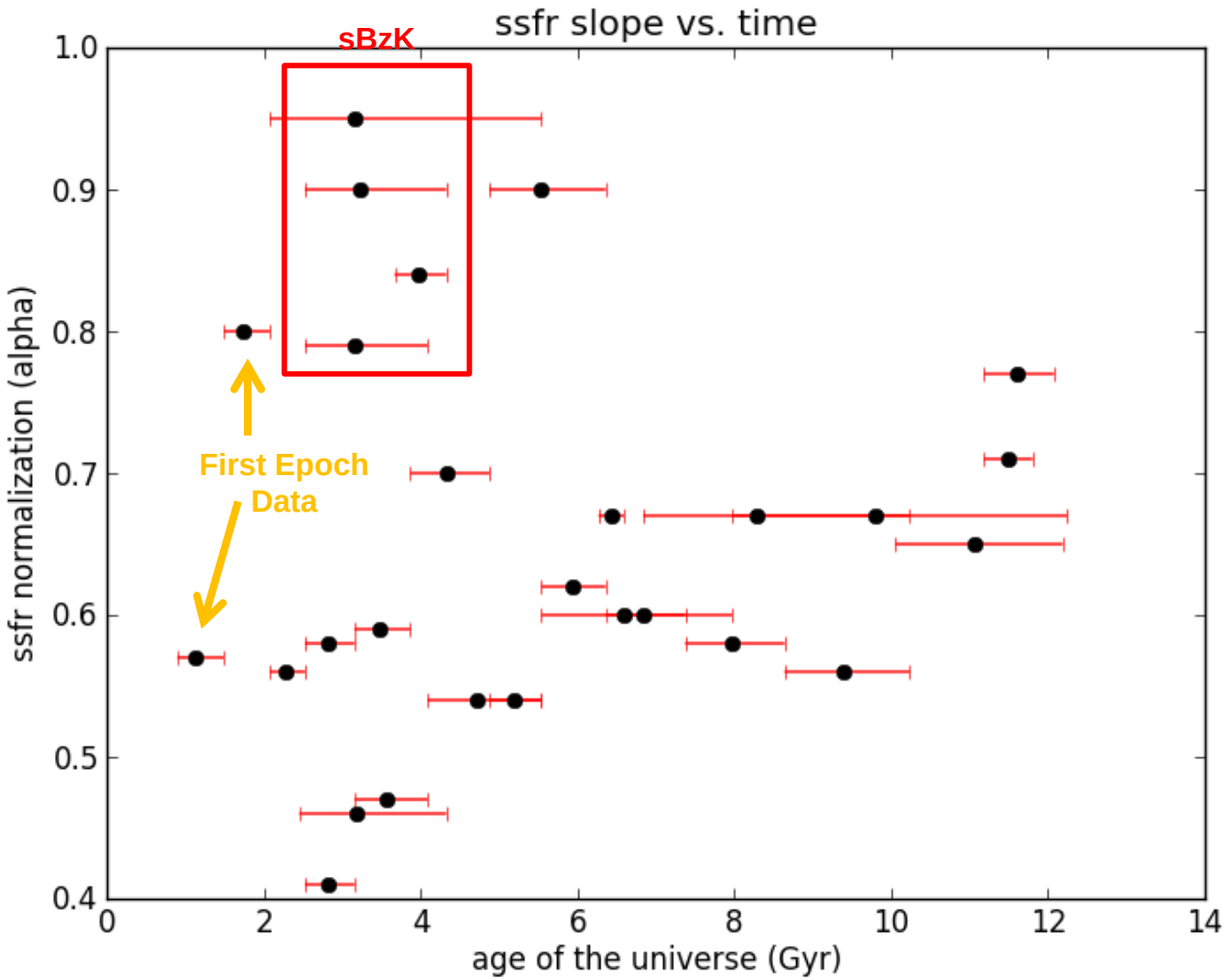
MS “Turnoff” (z~5)



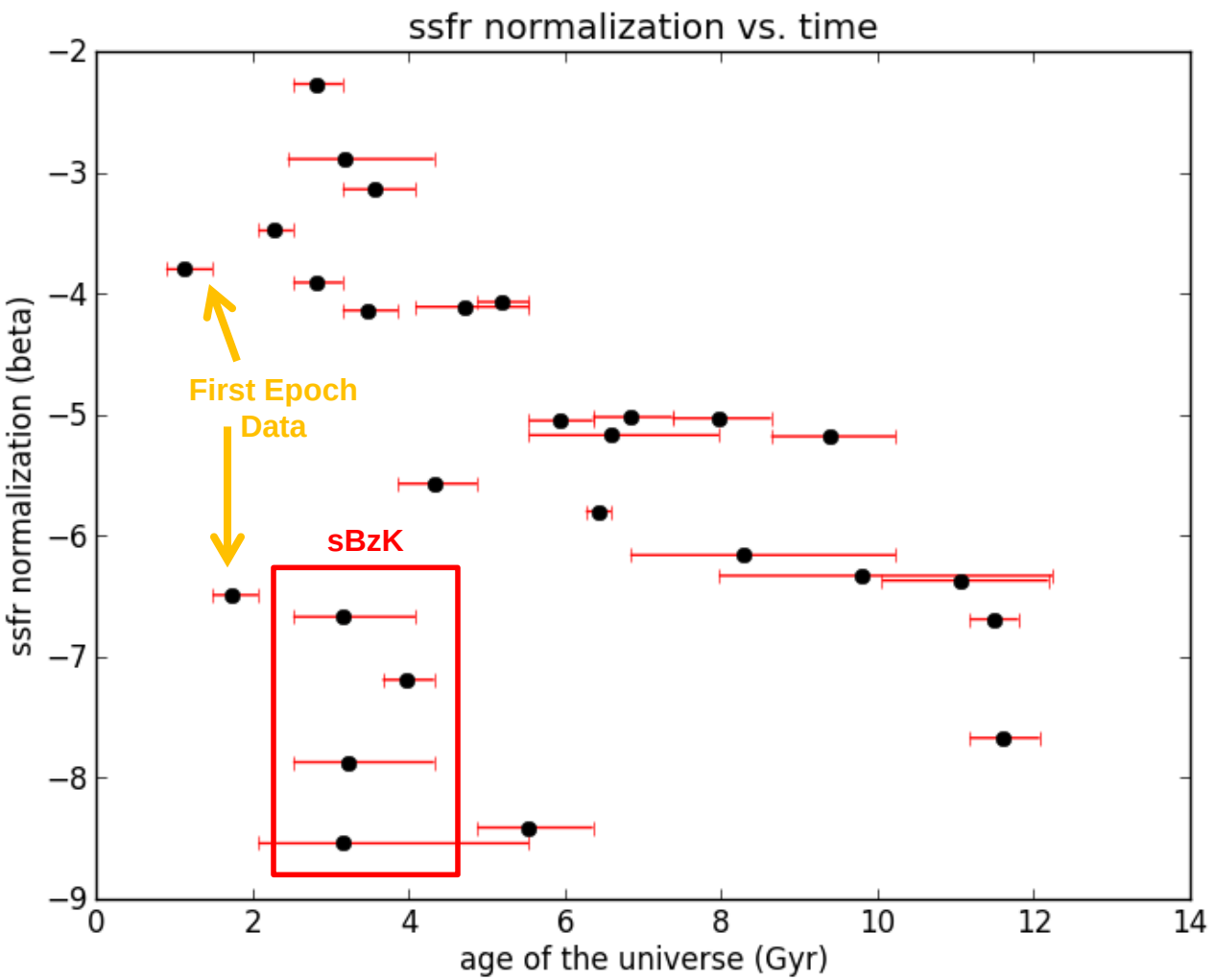
Questions We Want to Answer

- Is the MS present at even earlier times?
- Are the current fits to the MS relationship correct?
- To what extent do SFR indicators and selection effects influence the observed MS?
  - Are results consistent with each other?
  - Is the MS an artifact of systematics?
- How does the MS evolve over time?
- Is there a relationship between MS galaxies and AGN?

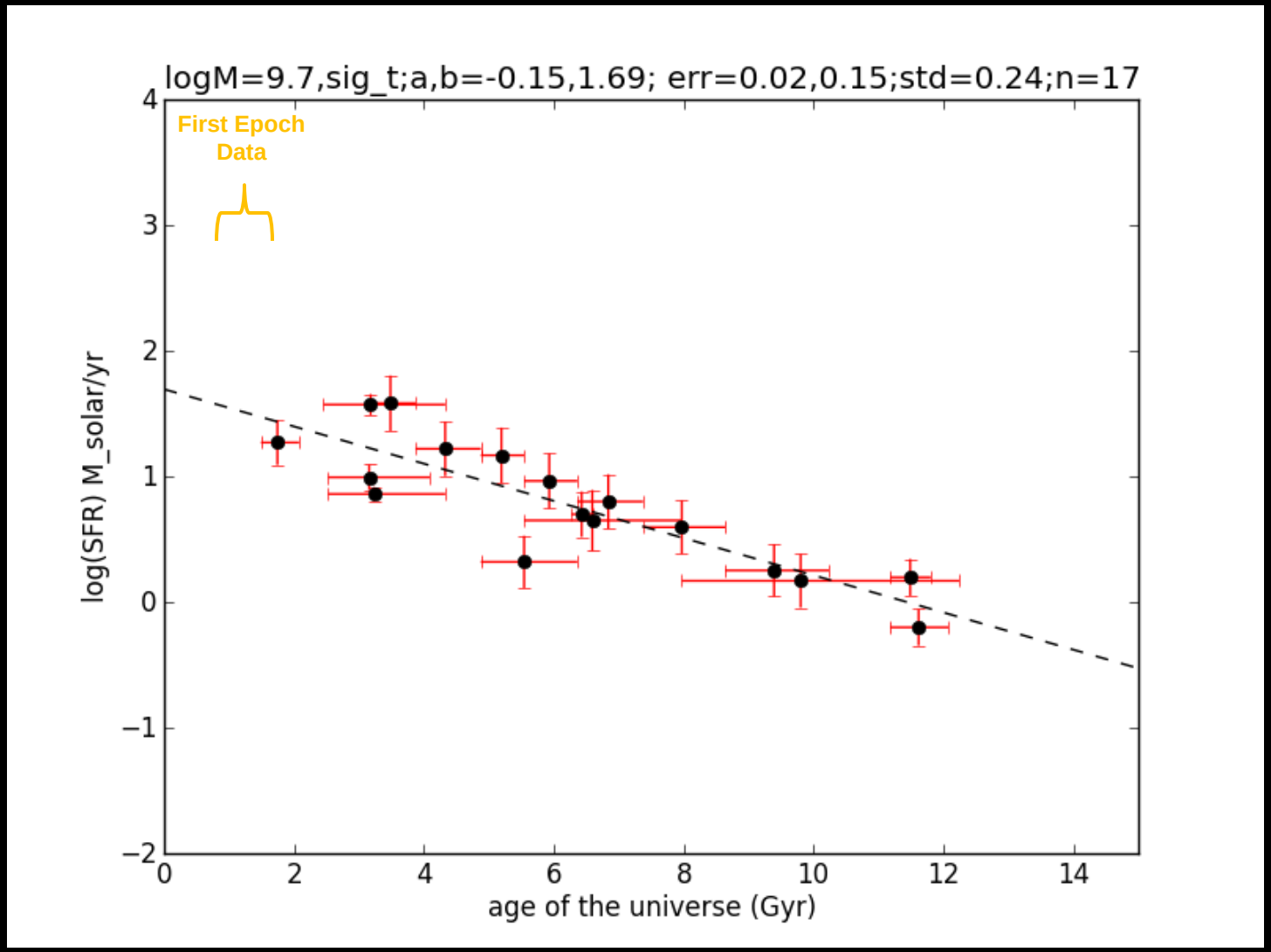
MS Evolution: Slope



MS Evolution: Slopes



MS Evolution: Mass Bins



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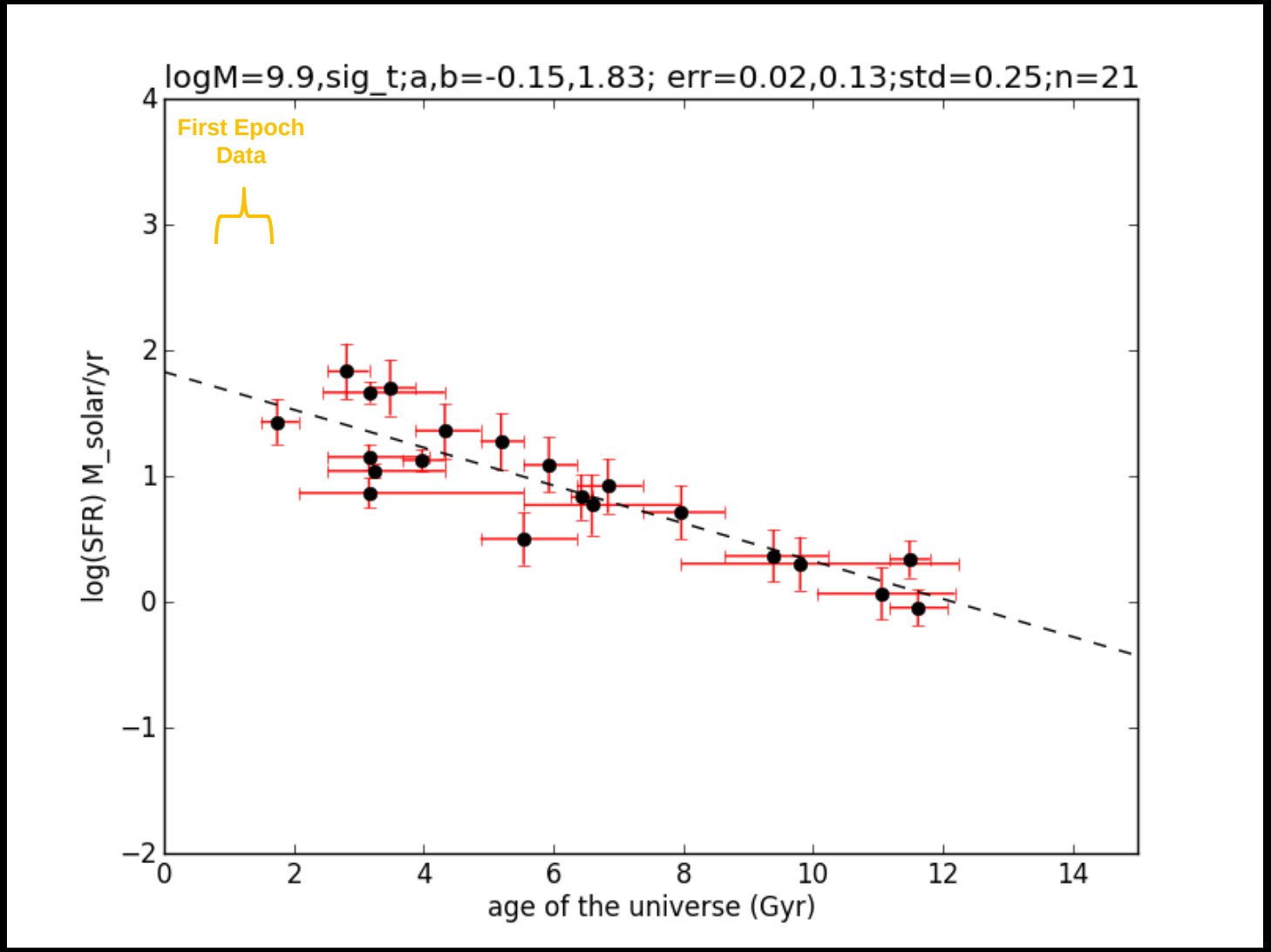

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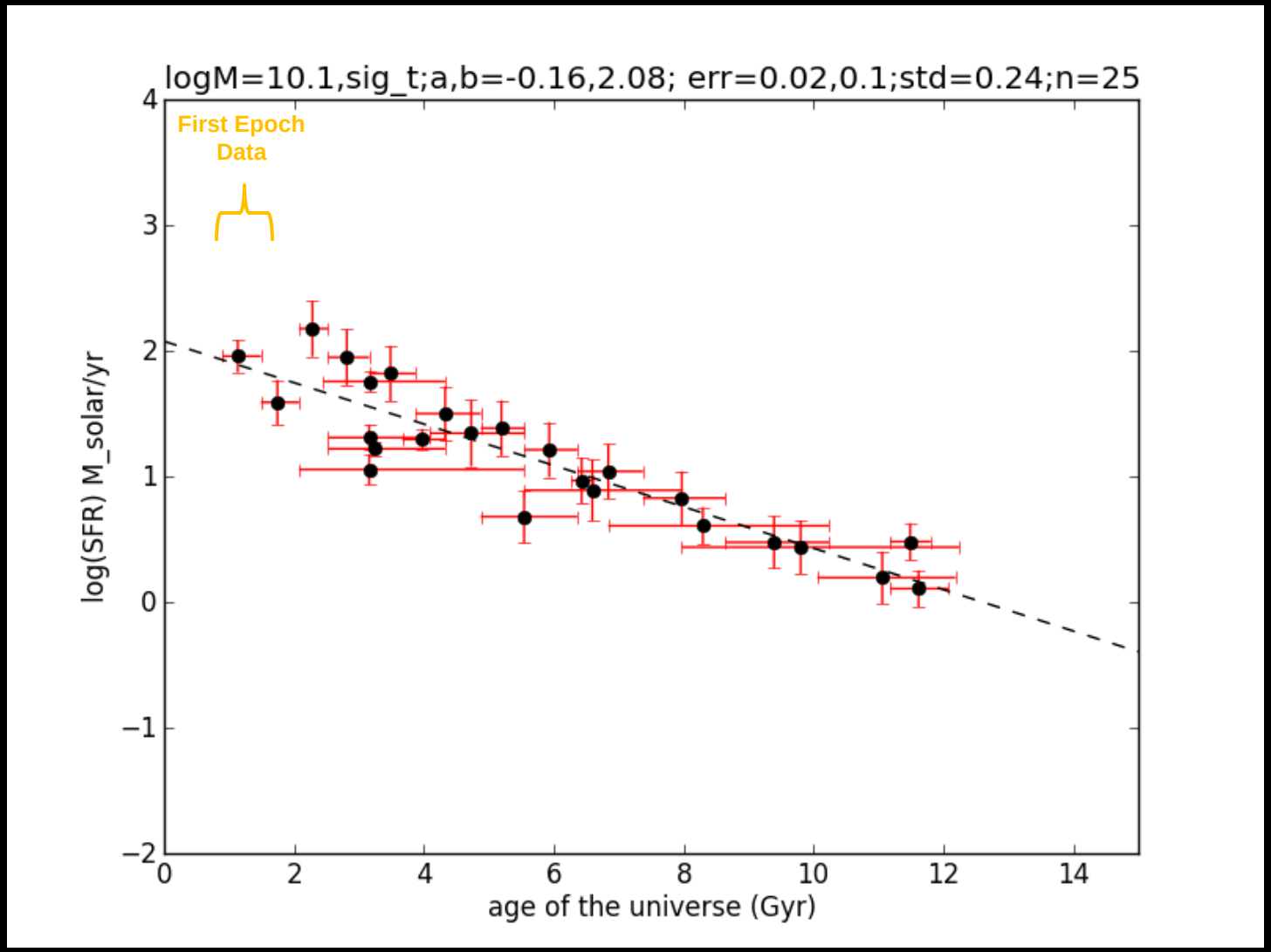

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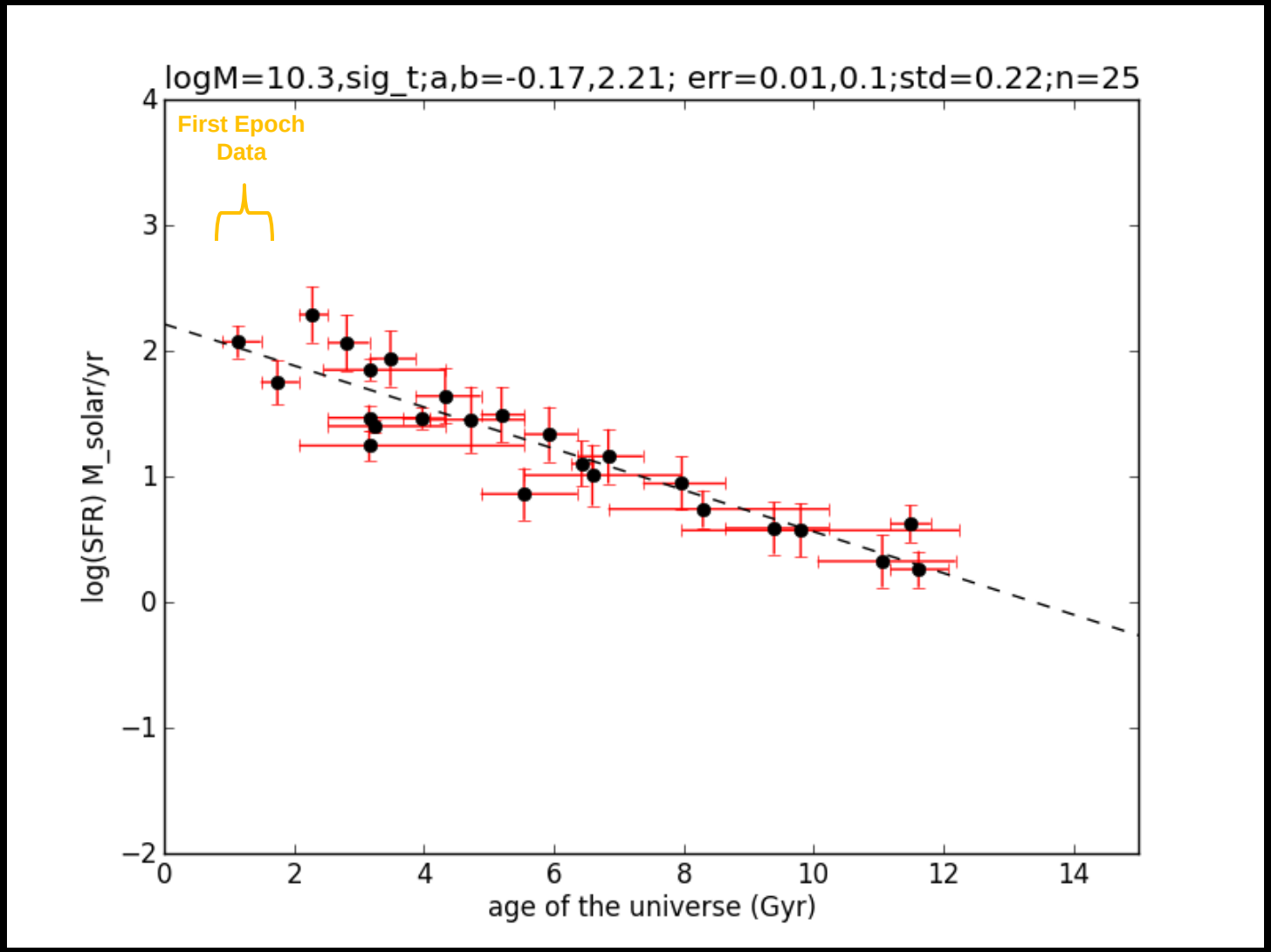

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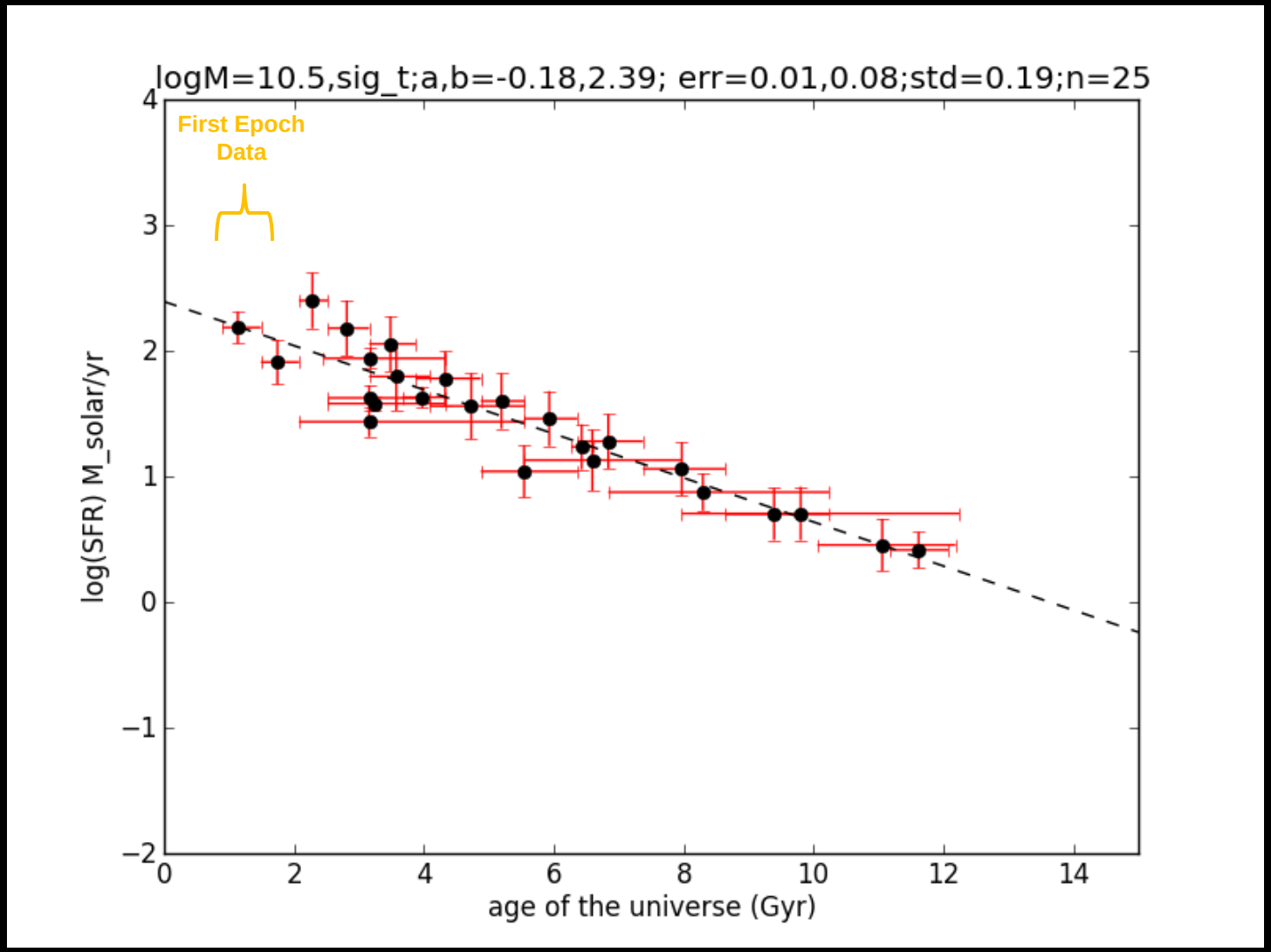
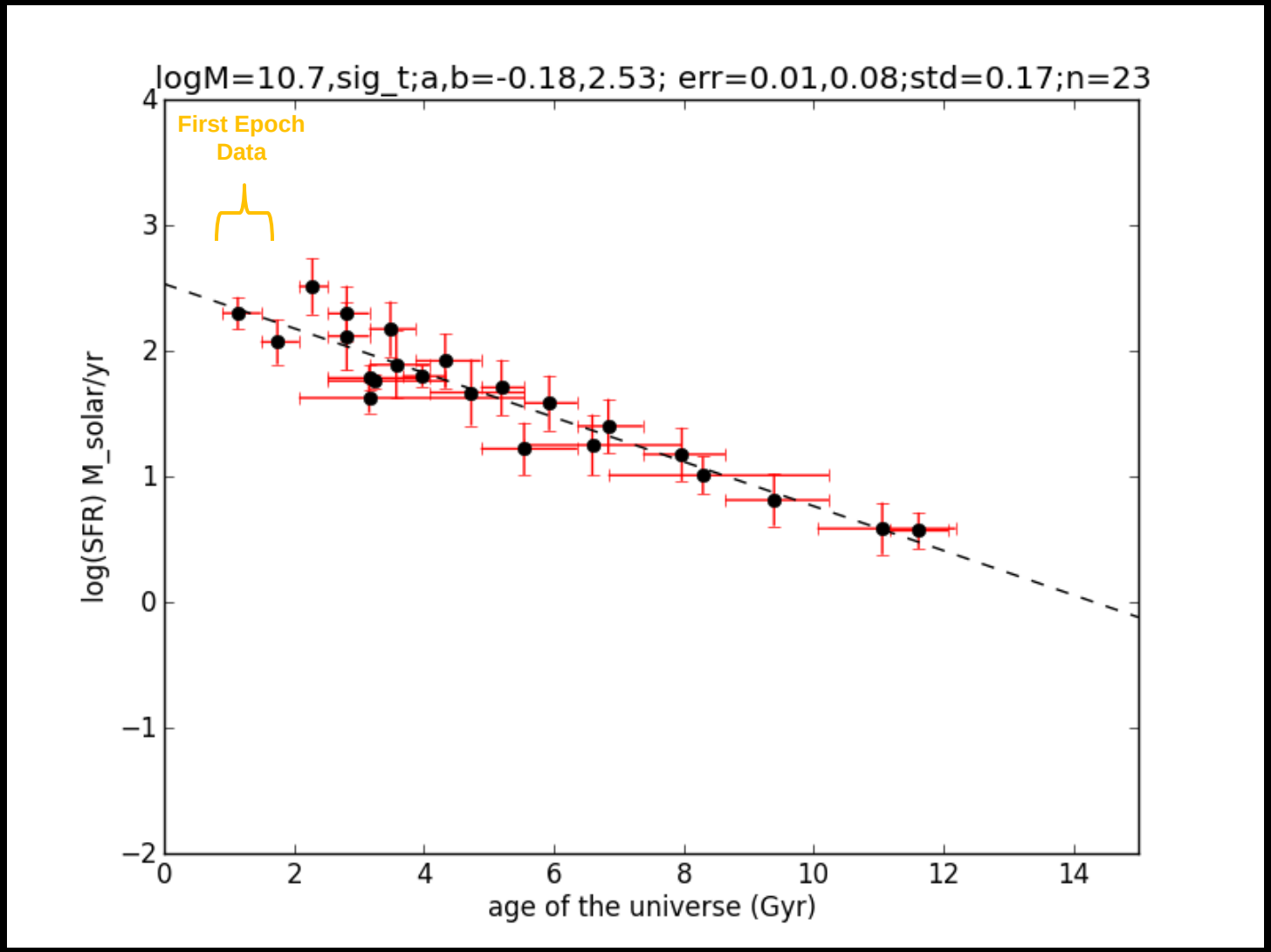


MS Evolution: Mass Bins



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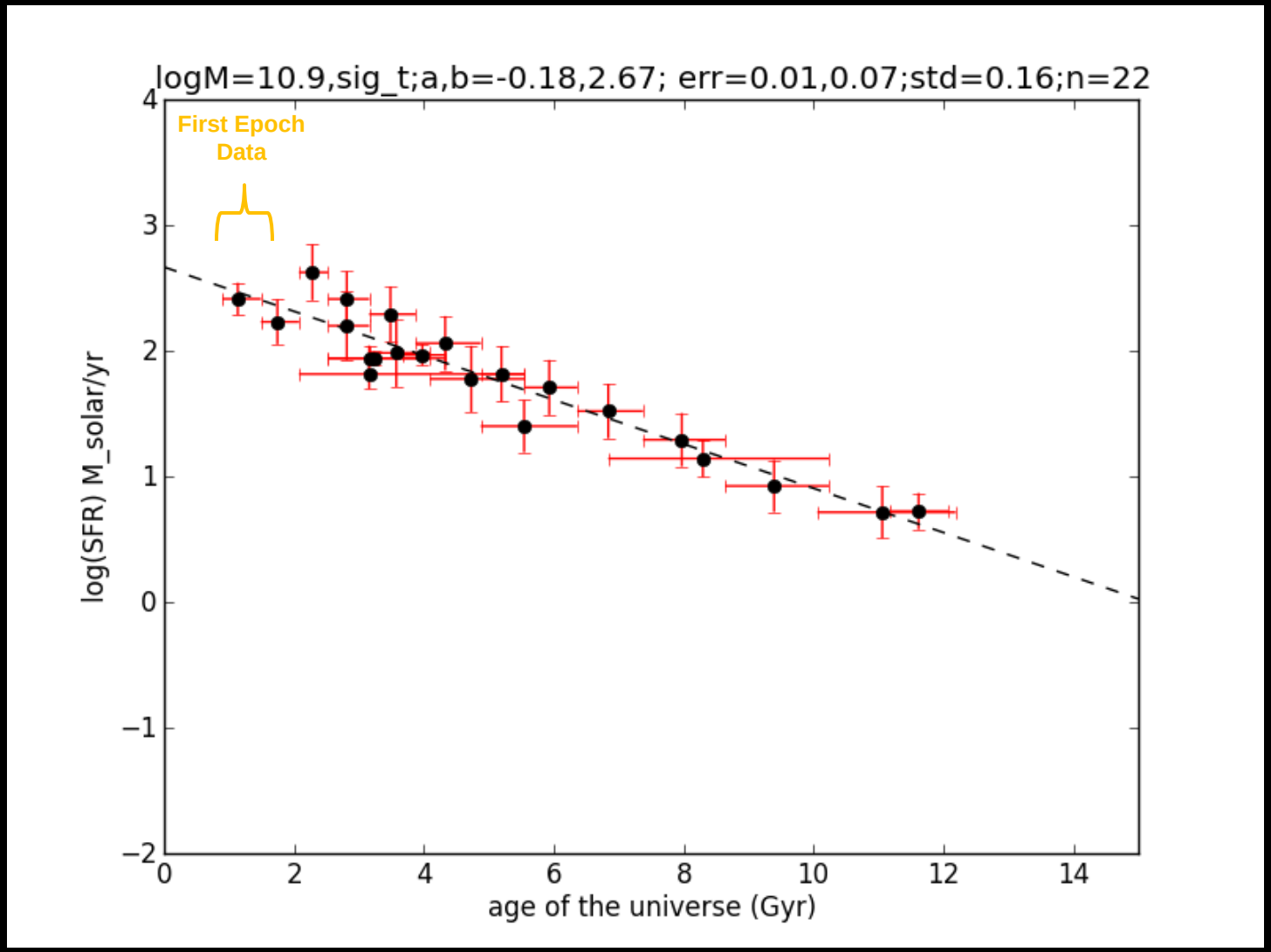

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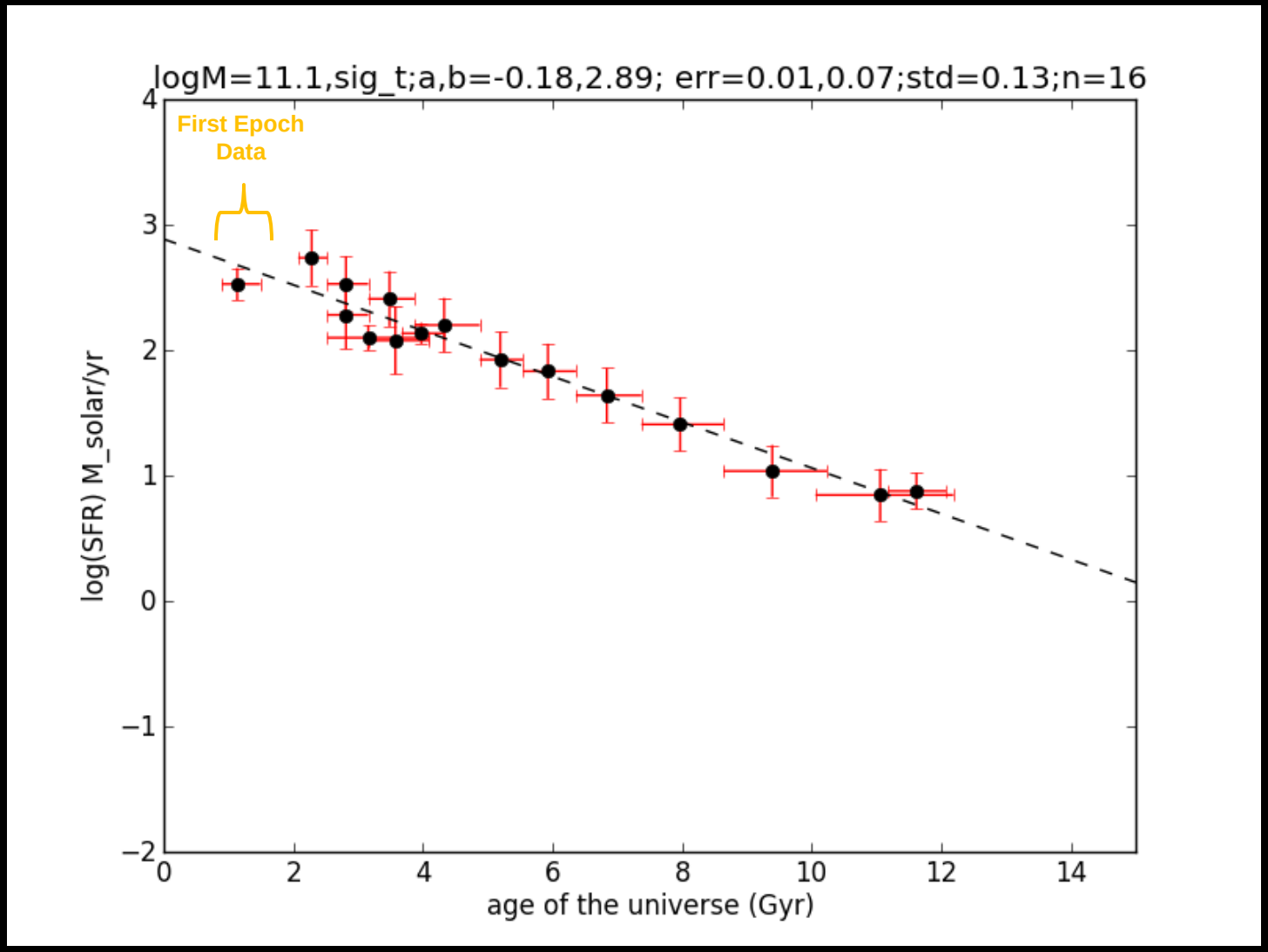


MS Evolution: Coefficients

Best fits for:

$$\log SFR = \alpha(t) \times \log M + \beta(t)$$

or

$$SFR = 10^{\beta(t)} \times M^{\alpha(t)}$$

$\alpha(t) = .64 + .002t$

Essentially constant

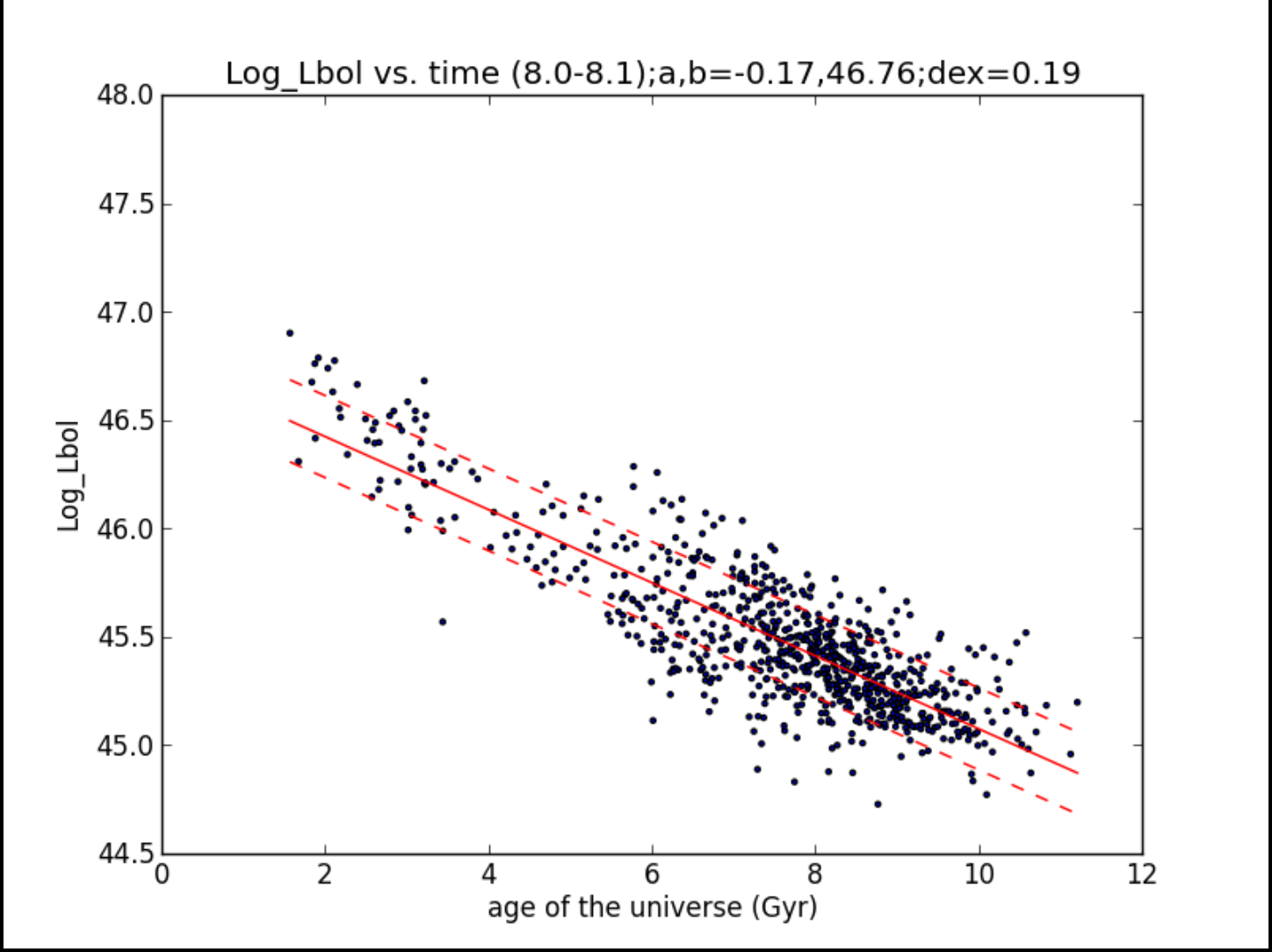
$\beta(t) = -4.38 - .193t$

Changes by ~2.5 orders of magnitude

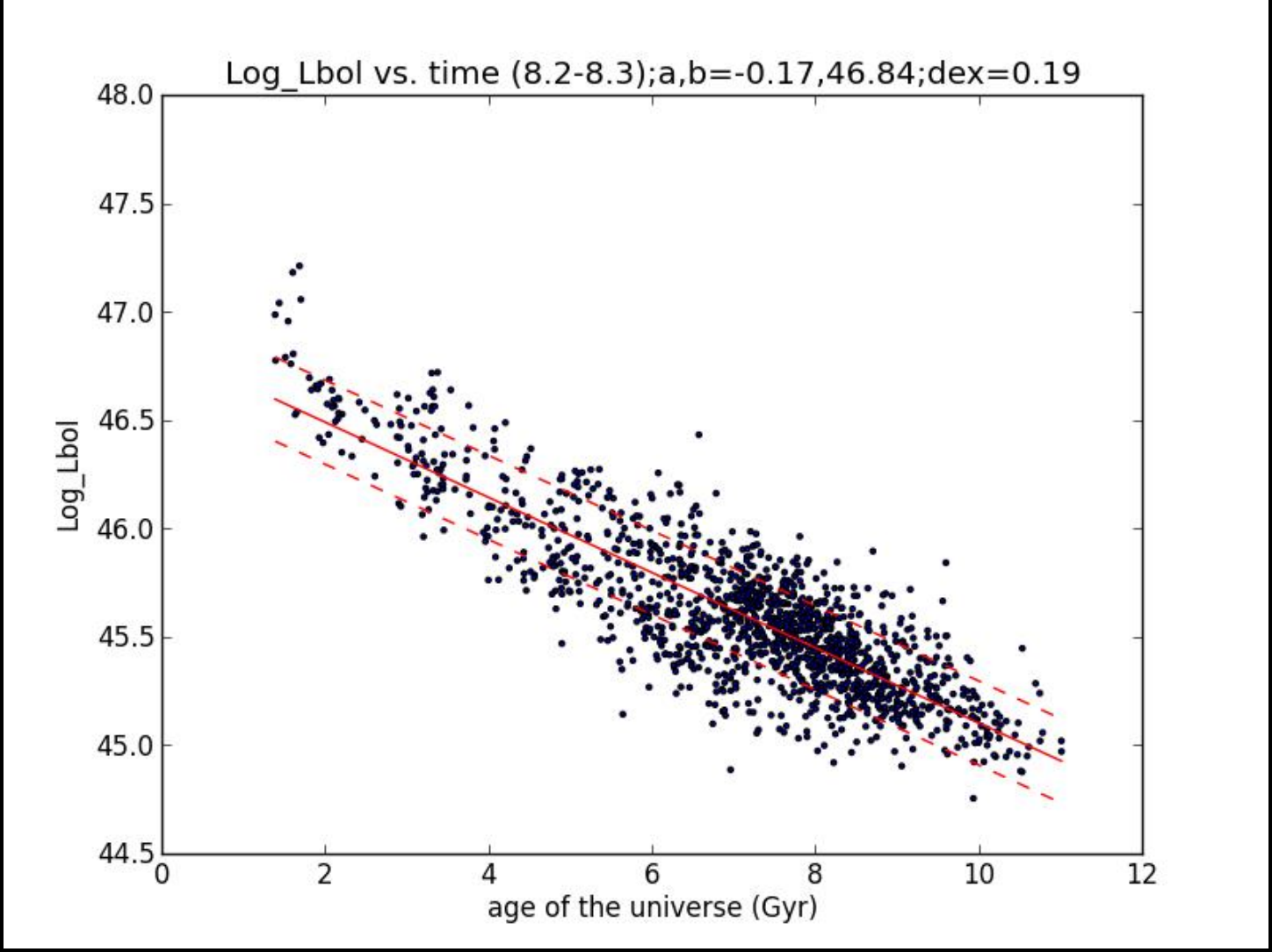
Questions We Want to Answer

- Is the MS present at even earlier times?
- Are the current fits to the MS relationship correct?
- To what extent do SFR indicators and selection effects influence the observed MS?
- How does the MS evolve over time?
- Is there a relationship between MS galaxies and AGN?
  - If so, what does this tell us about galaxy evolution?

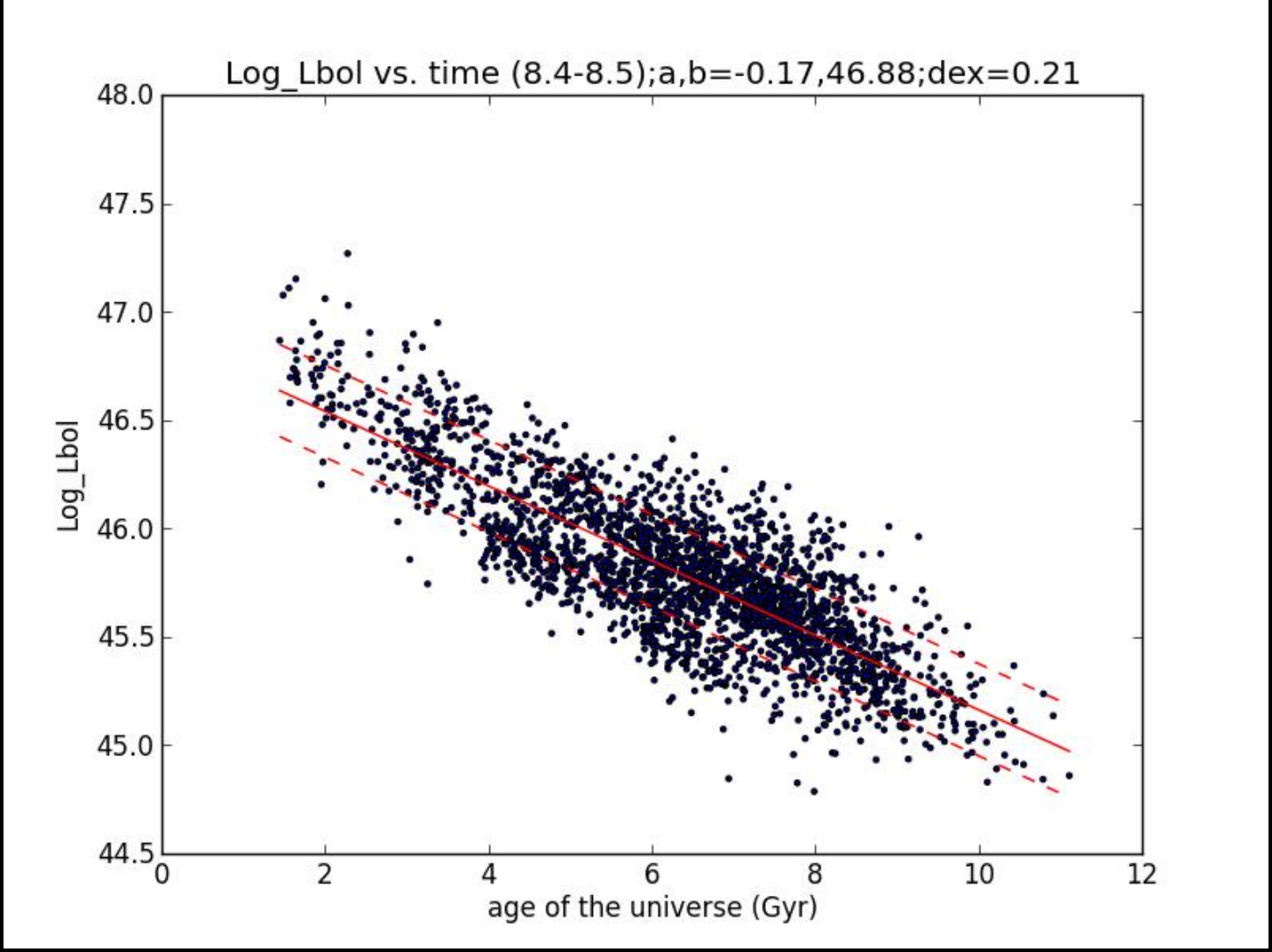
Quasar Evolution: Mass Bins



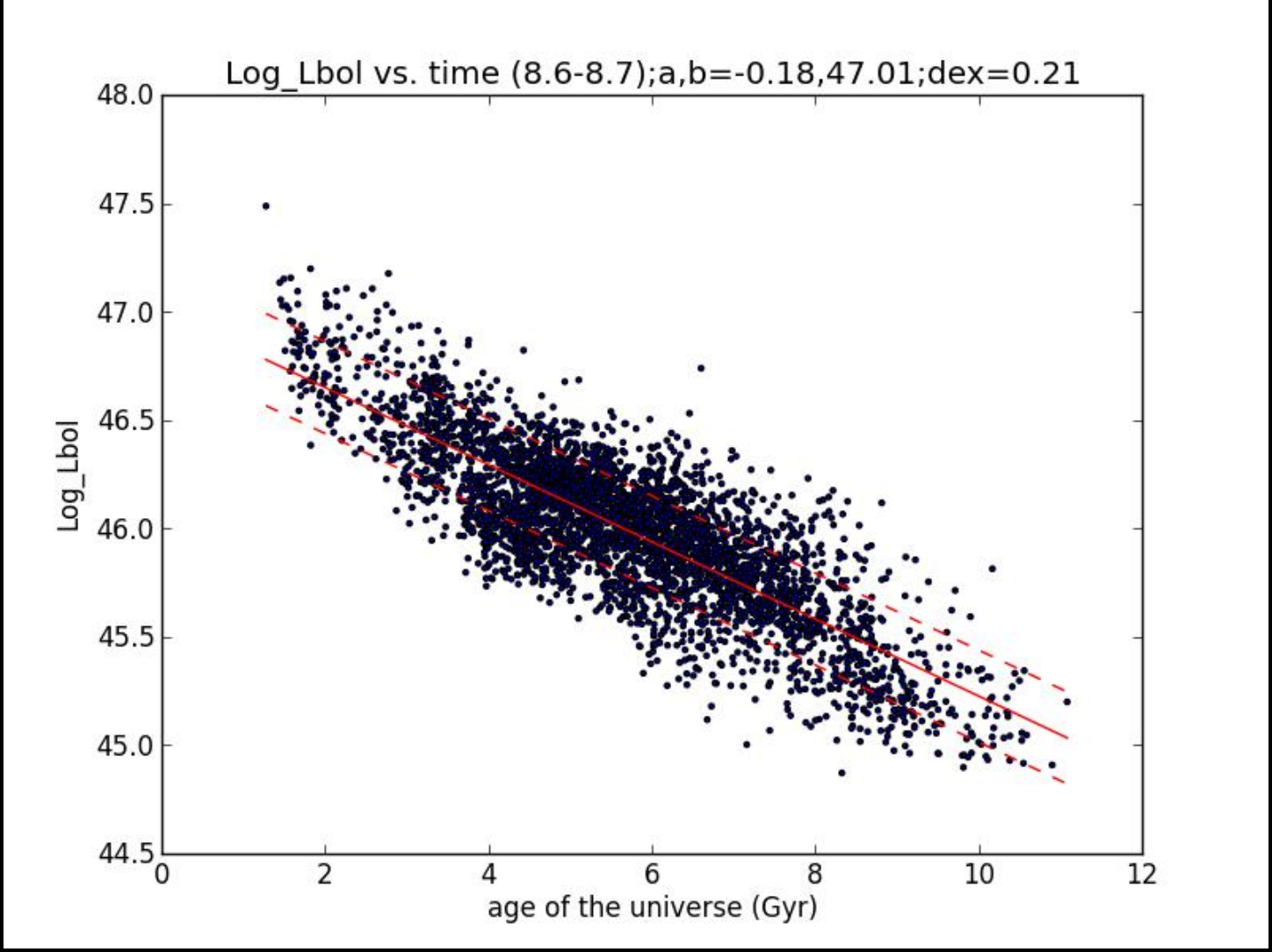
Quasar Evolution: Mass Bins



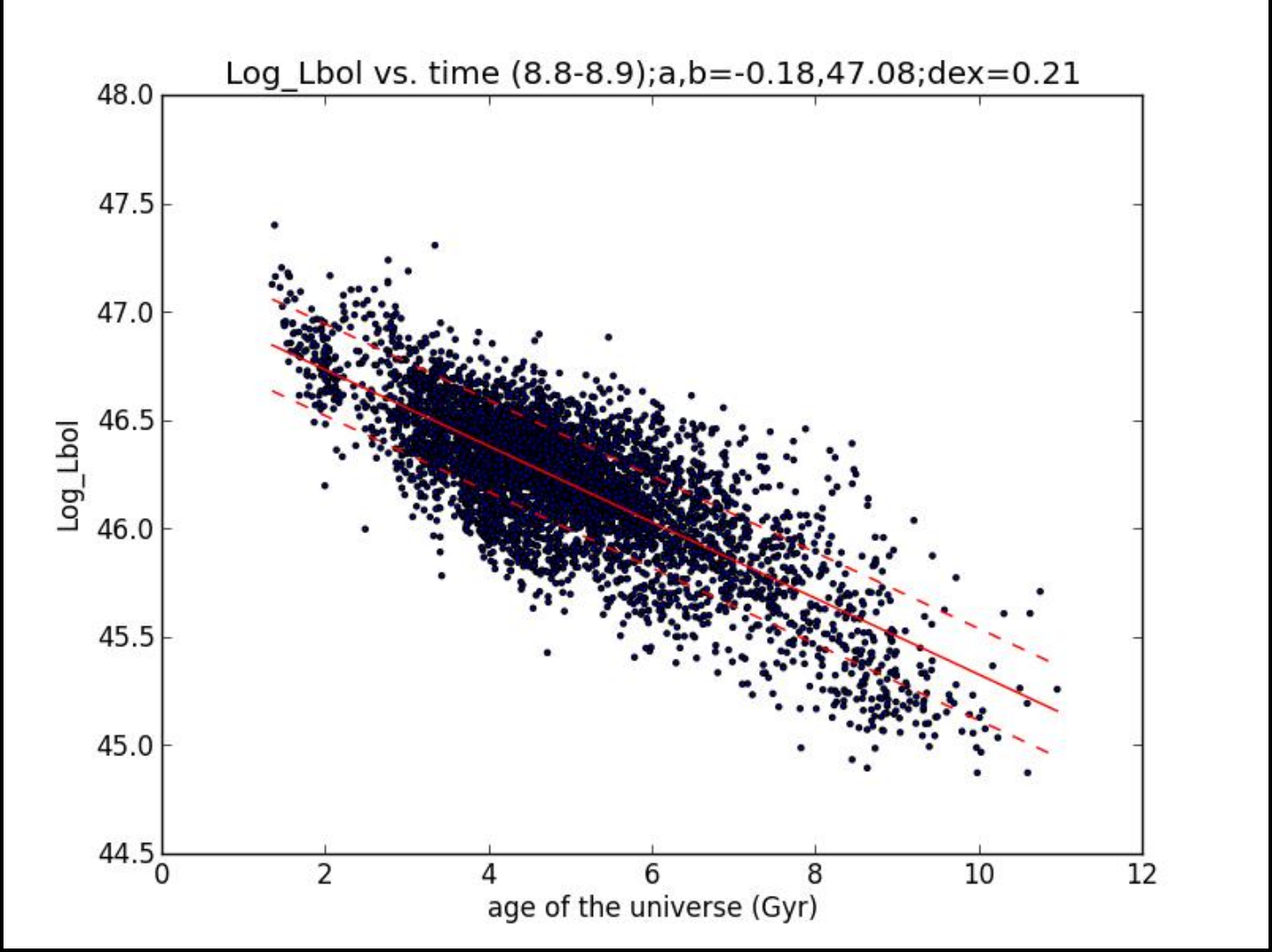
Quasar Evolution: Mass Bins



Quasar Evolution: Mass Bins



Quasar Evolution: Mass Bins



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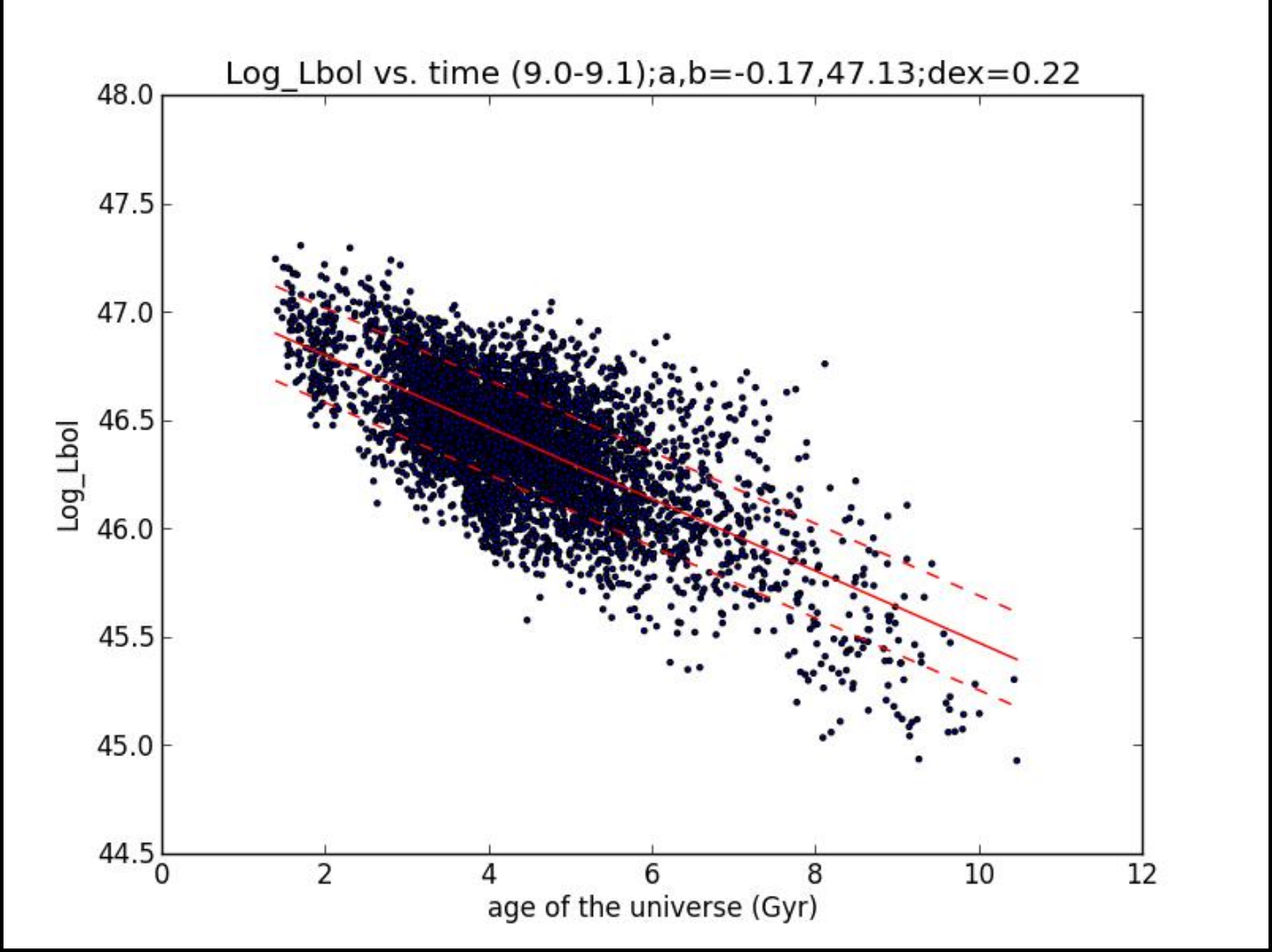
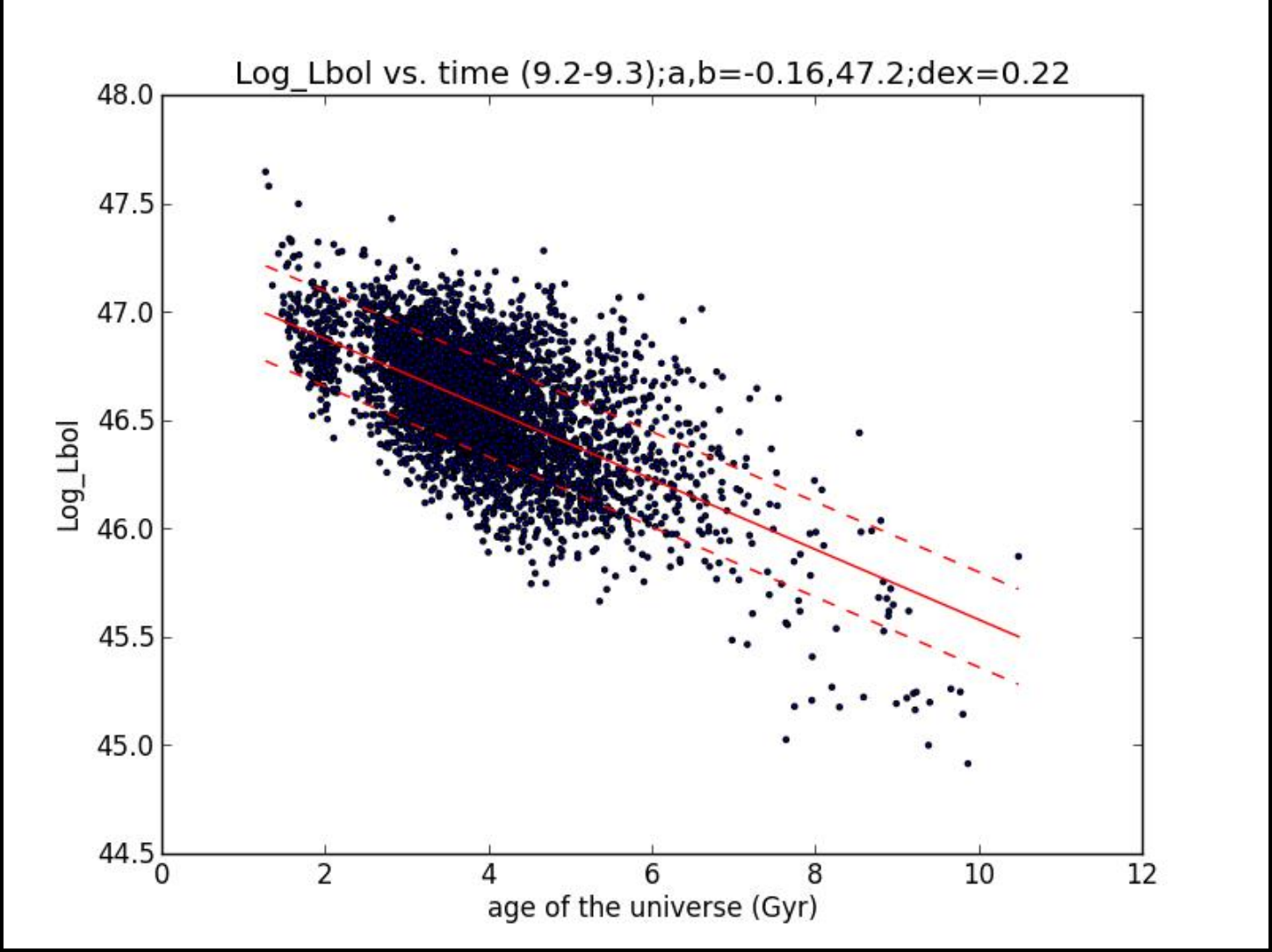


Quasar Evolution: Mass Bins



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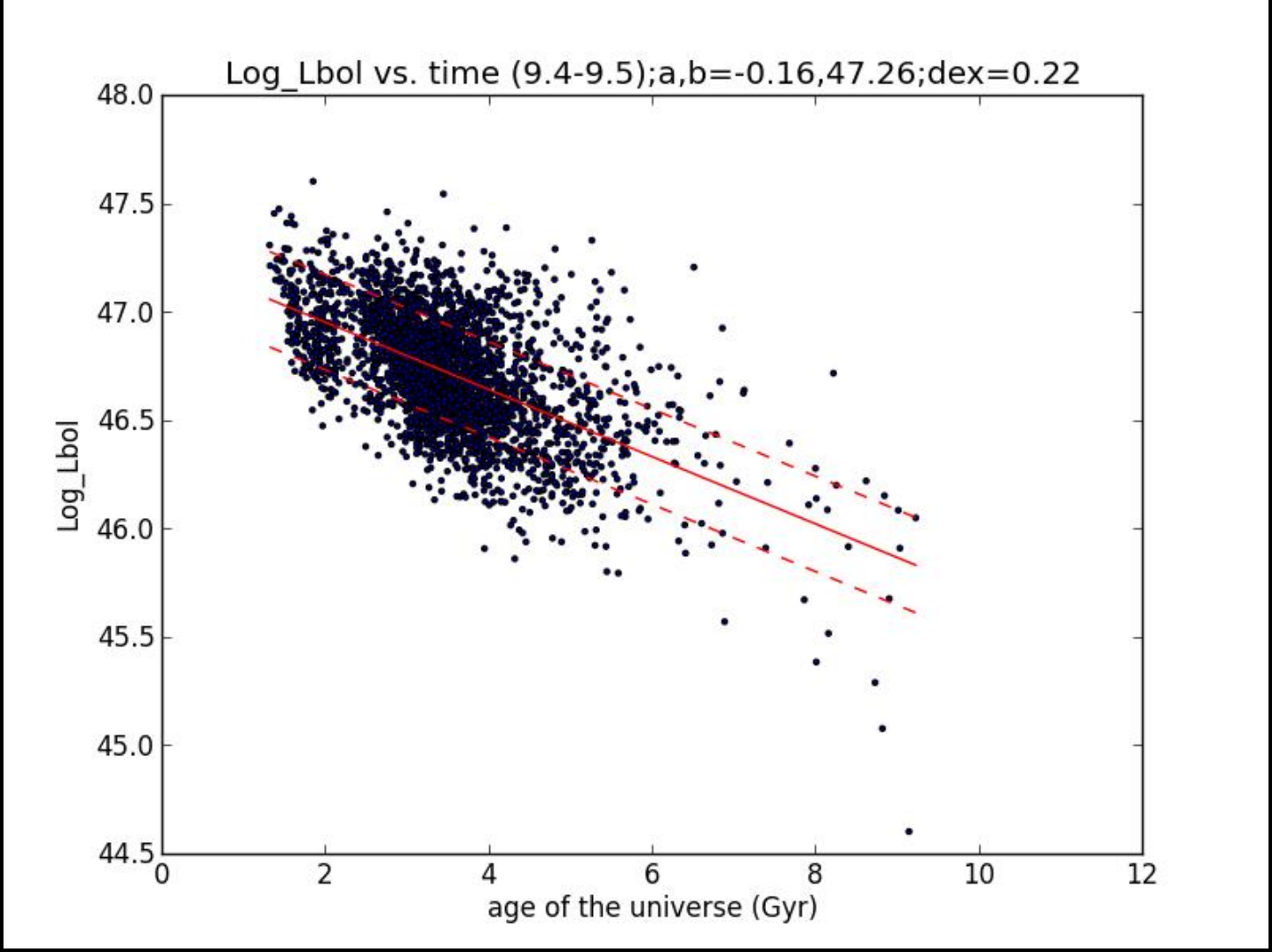


Quasar Evolution: Coefficients

Best fits for:

$$\log L_{bol} = \alpha(t) \times \log M + \beta(t)$$

or

$$L_{bol} = 10^{\beta(t)} \times M^{\alpha(t)}$$

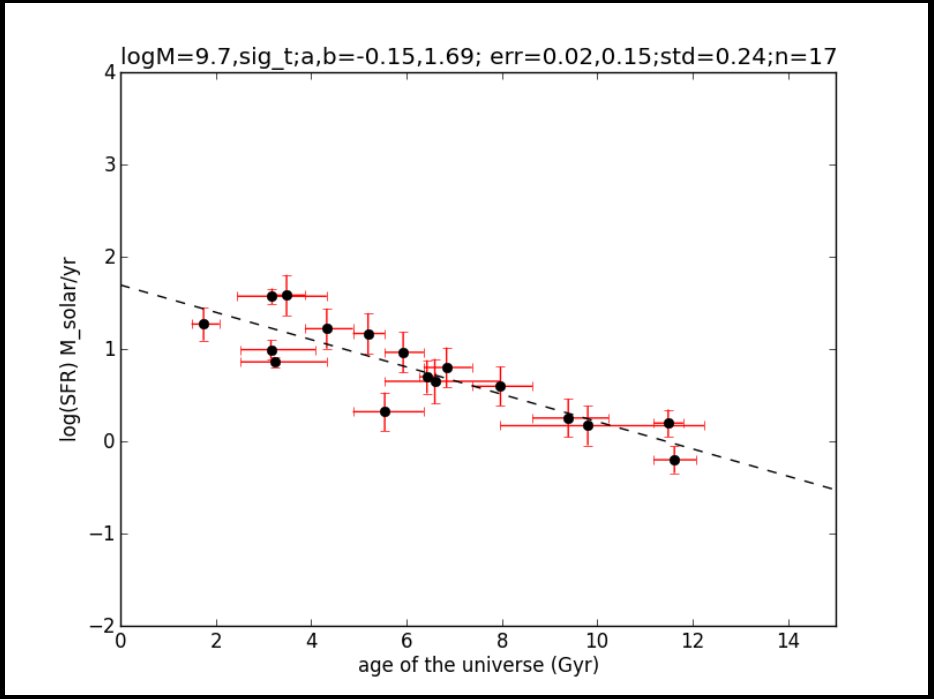
$\alpha(t) = .40 + .001t$

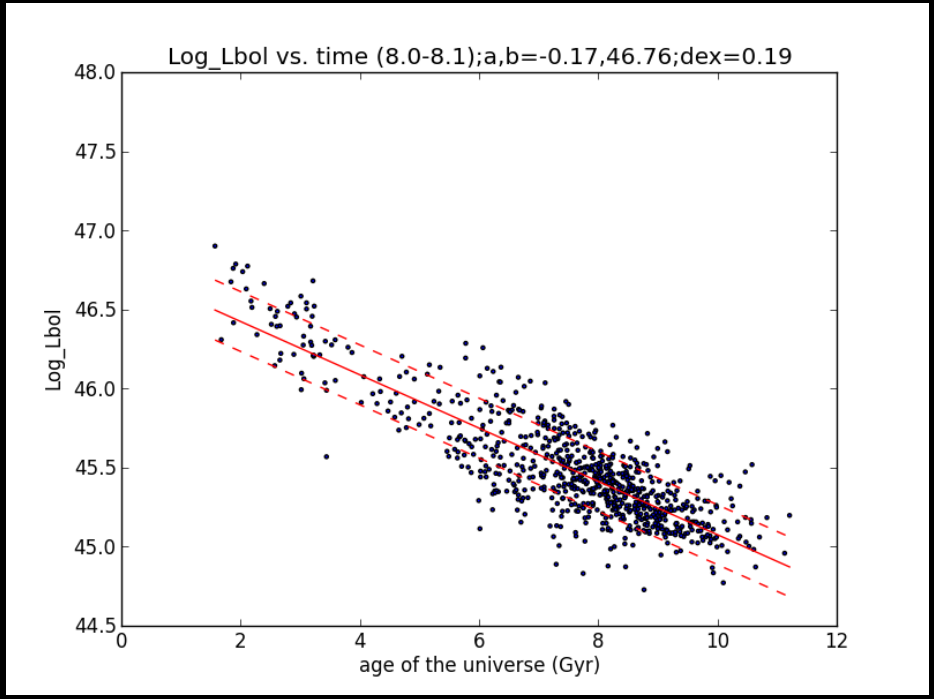
Essentially constant

$\beta(t) = 43.53 - .179t$

Changes by ~2.5 orders of magnitude

Quasar/MS Evolution Comparison





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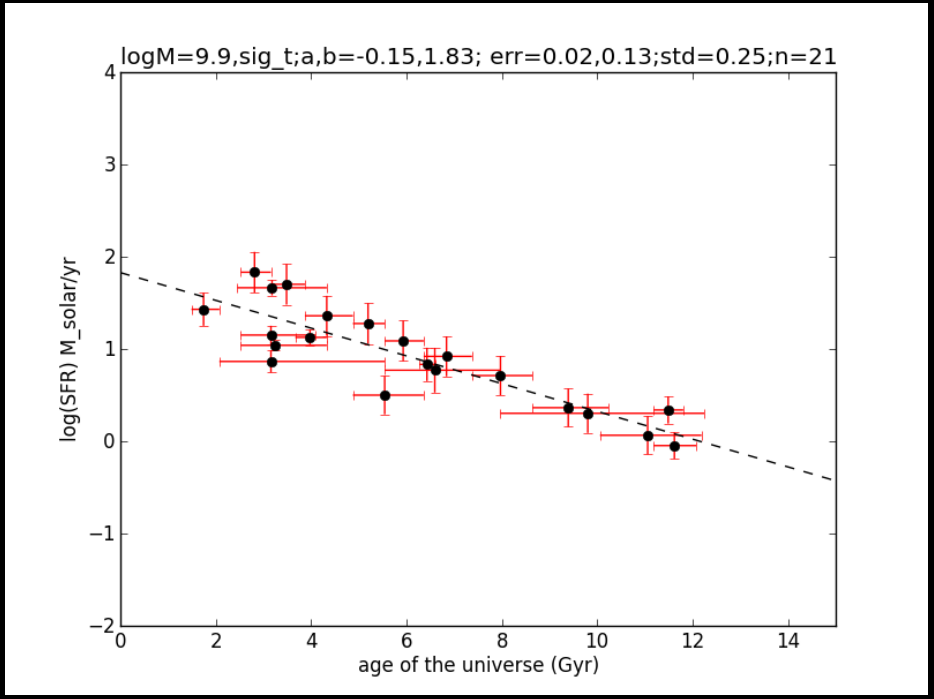

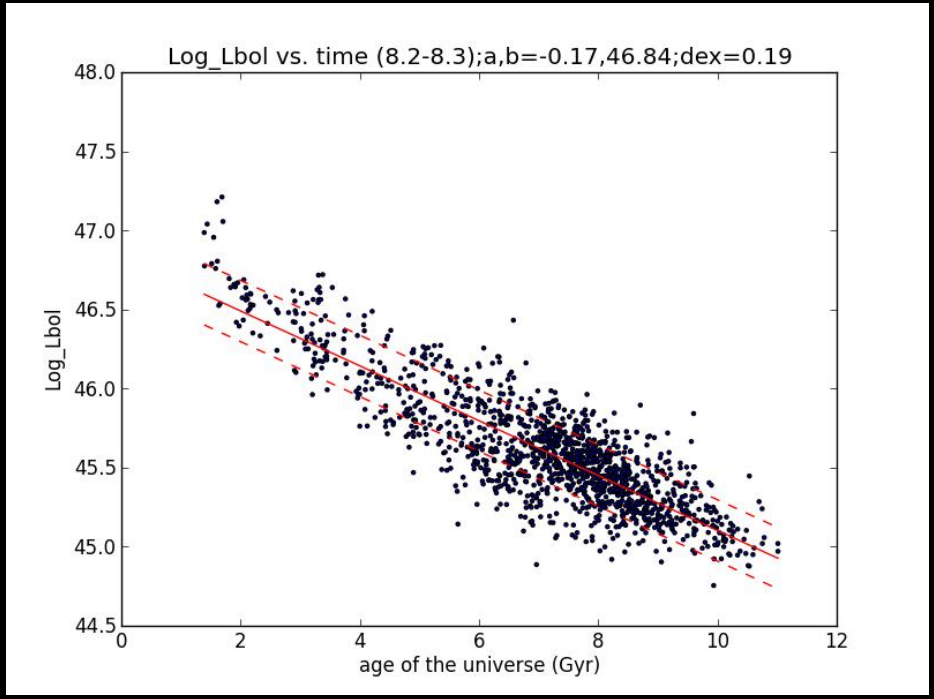

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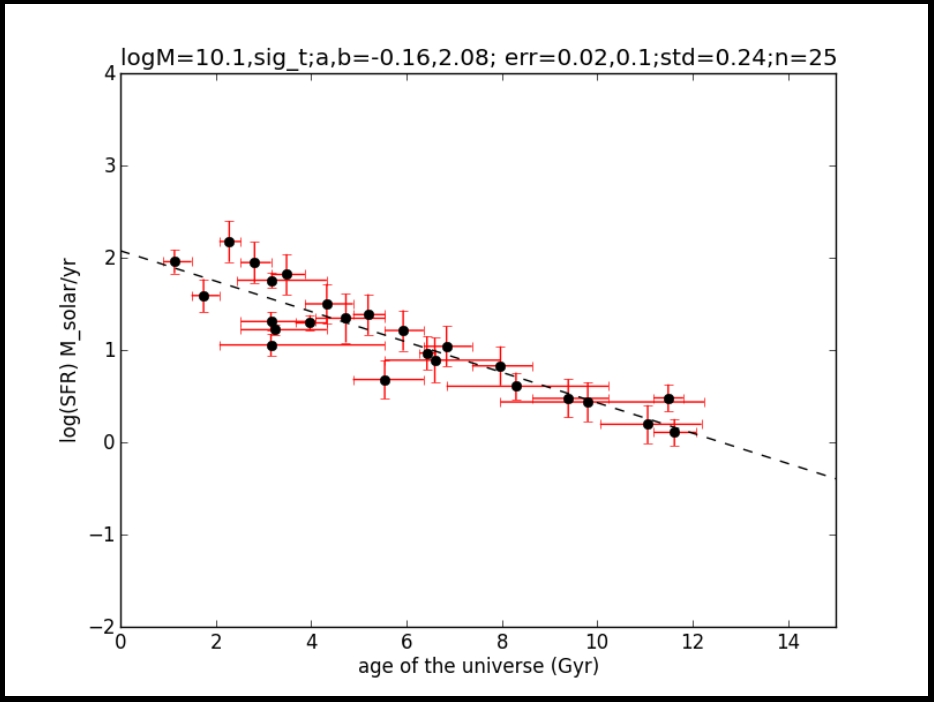

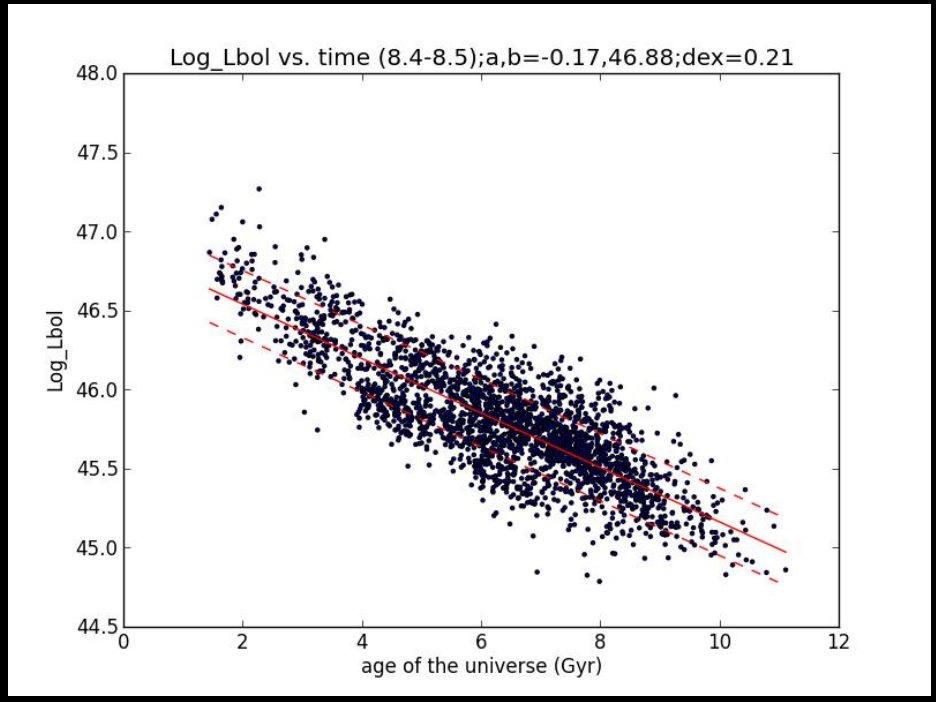

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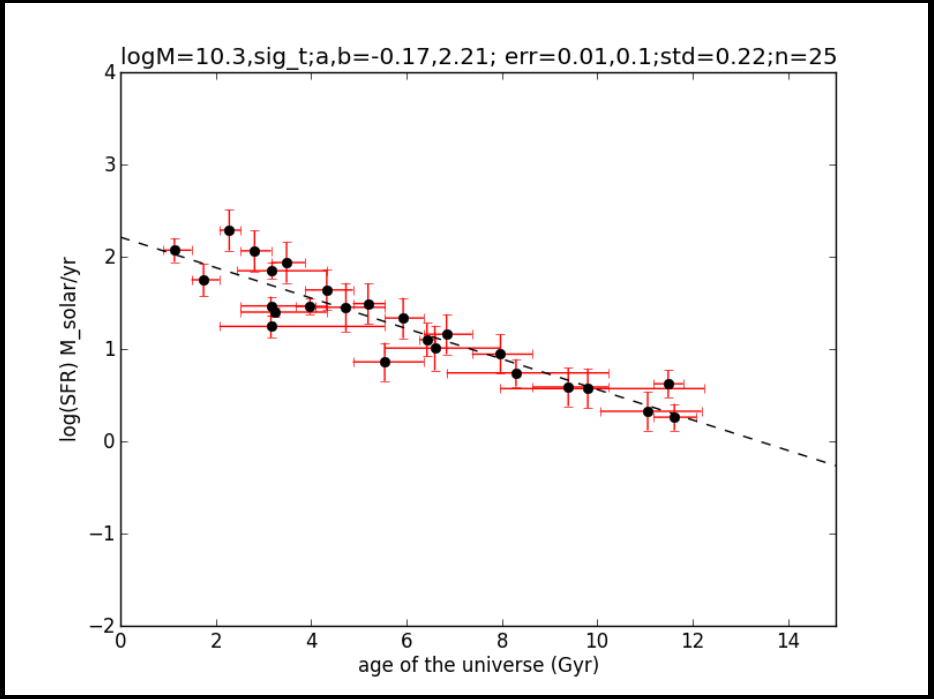

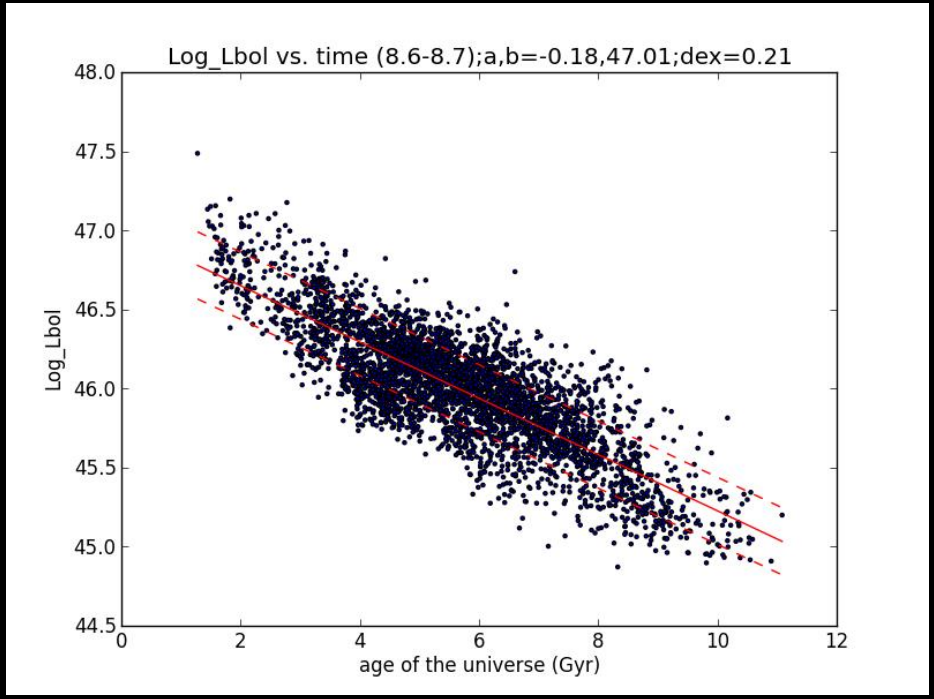

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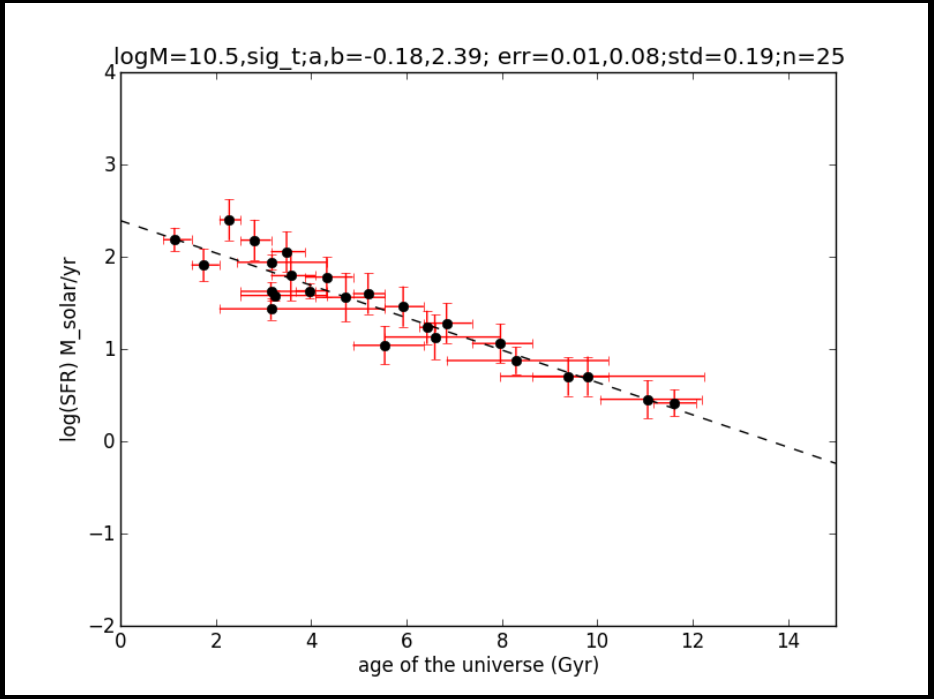

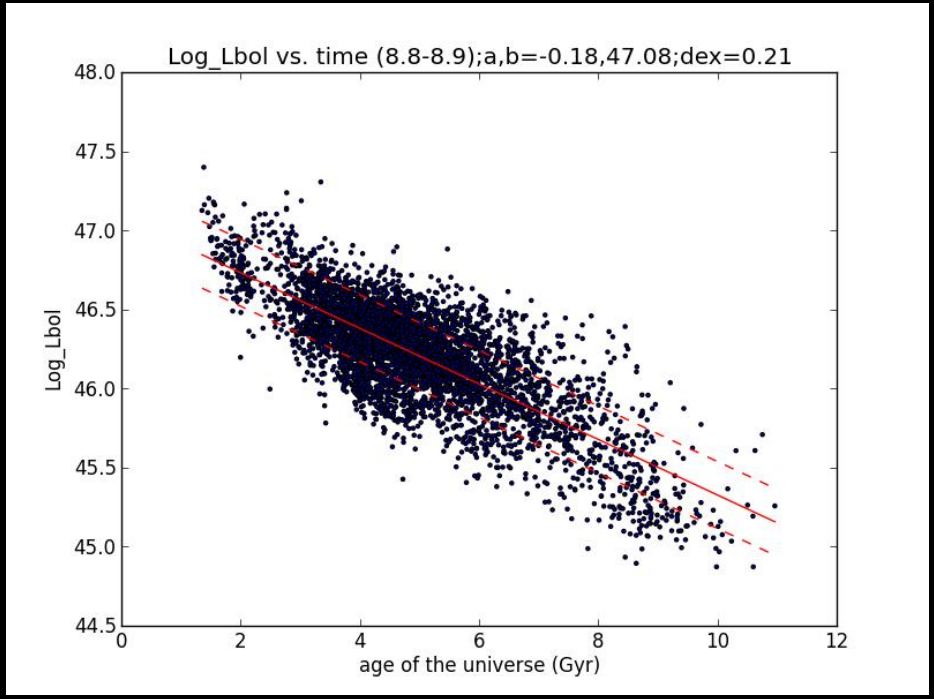

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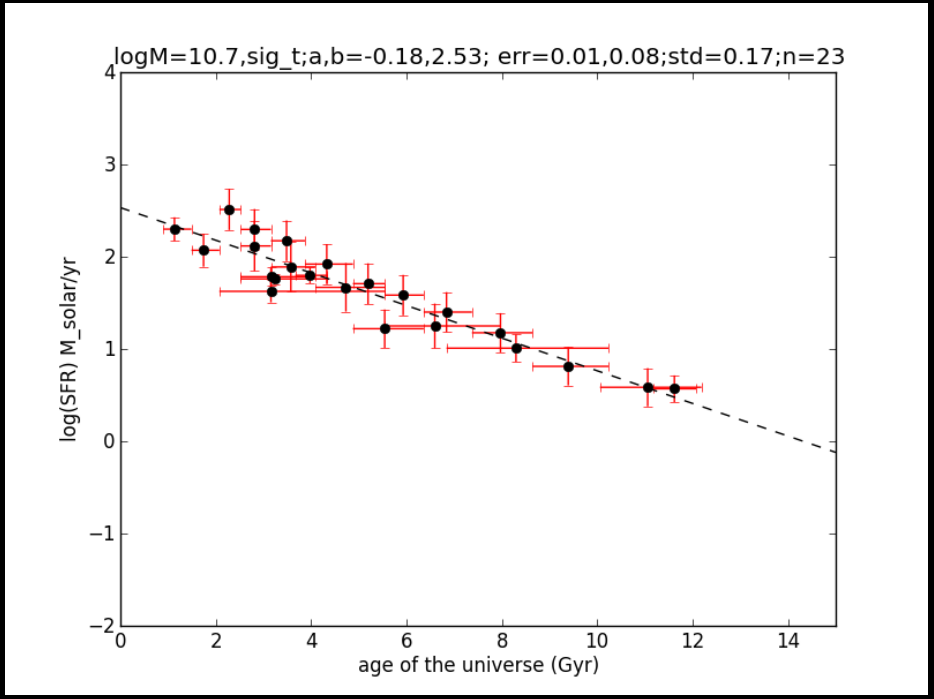

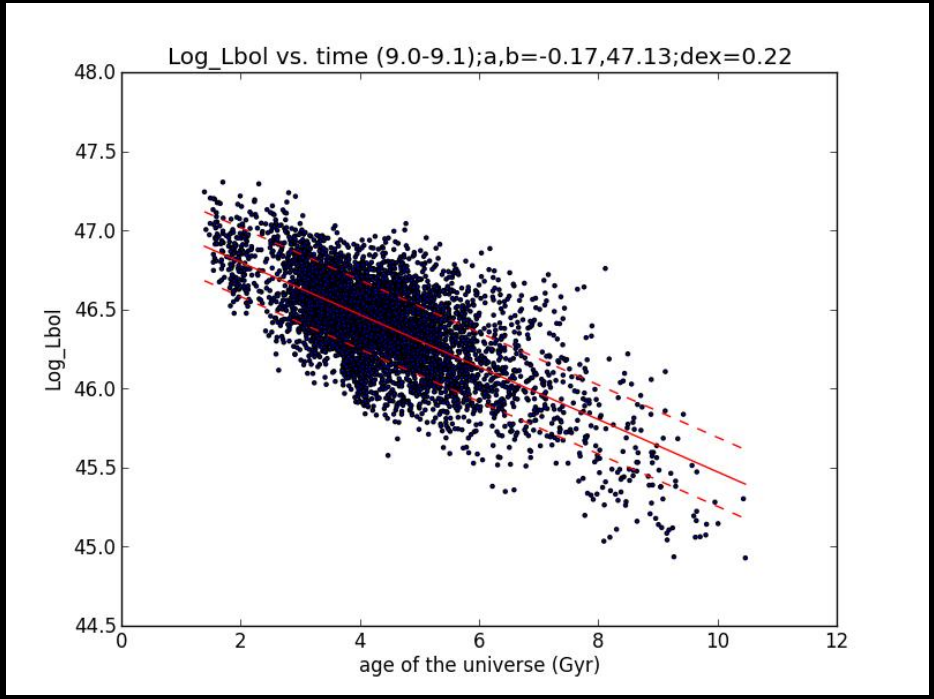

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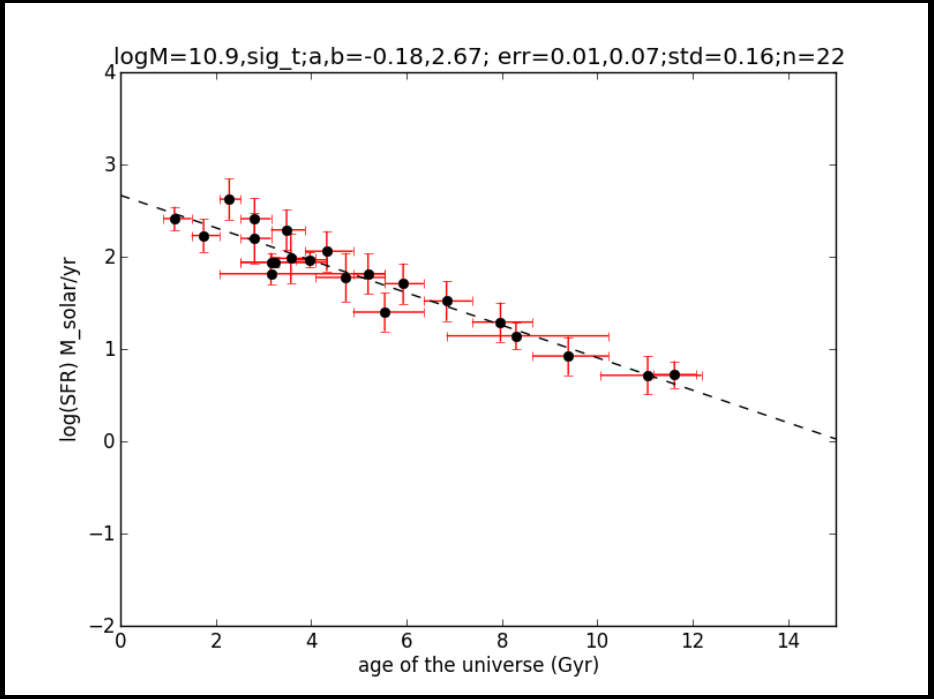

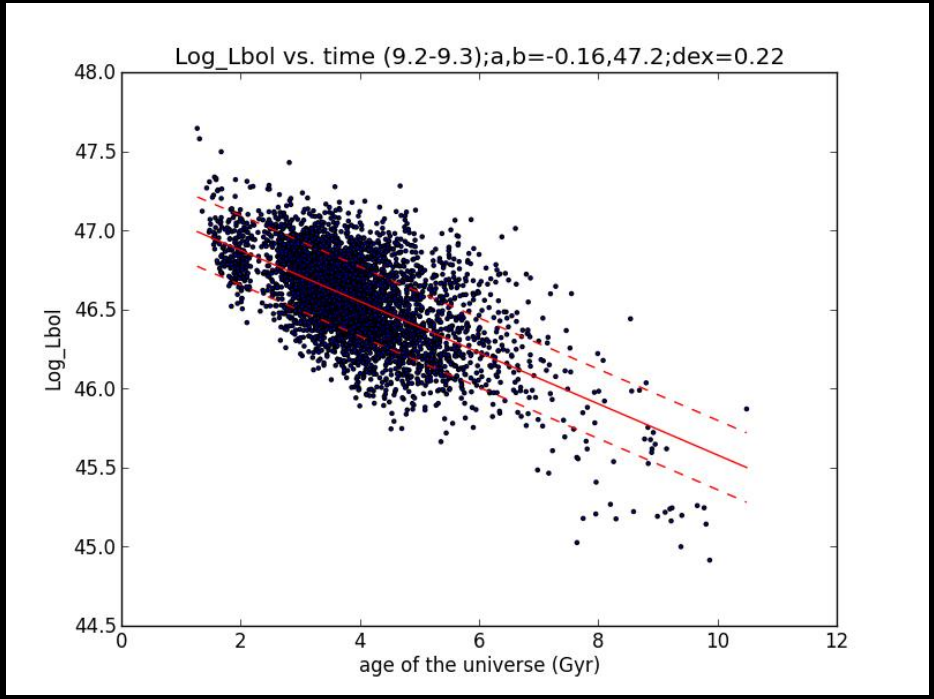

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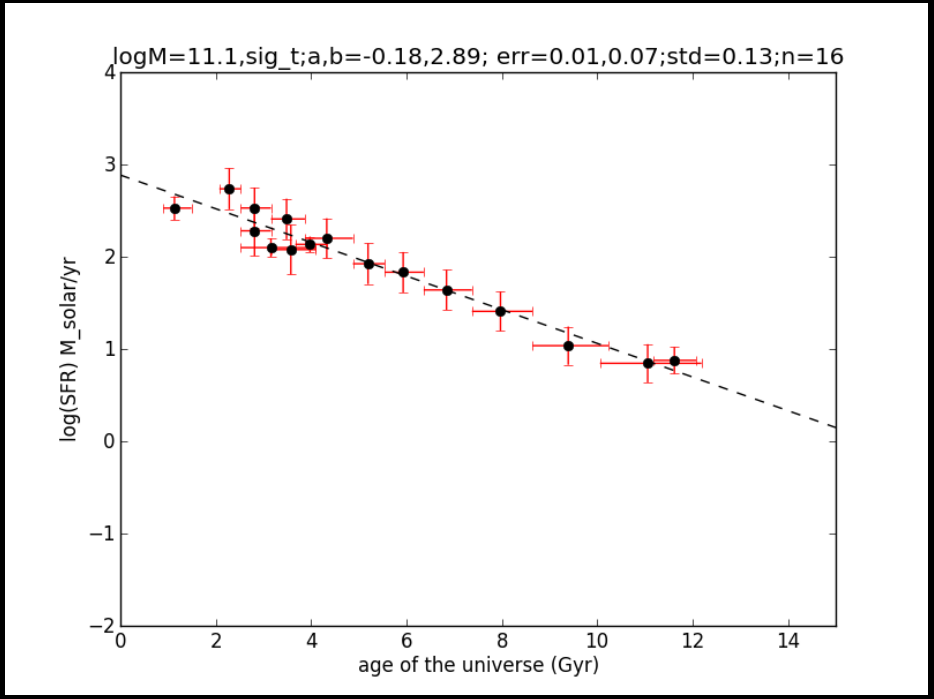
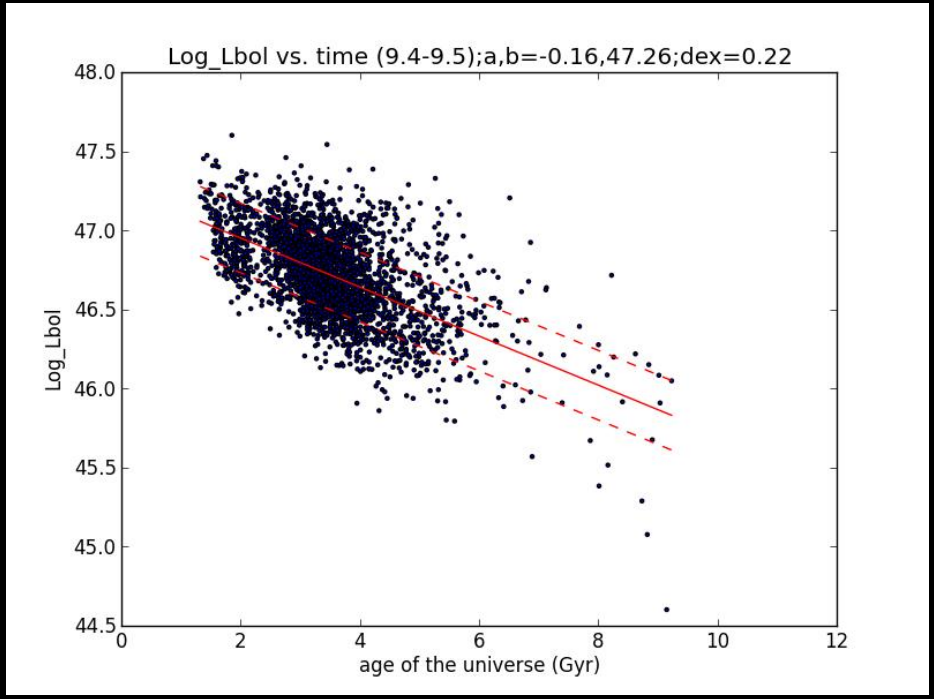


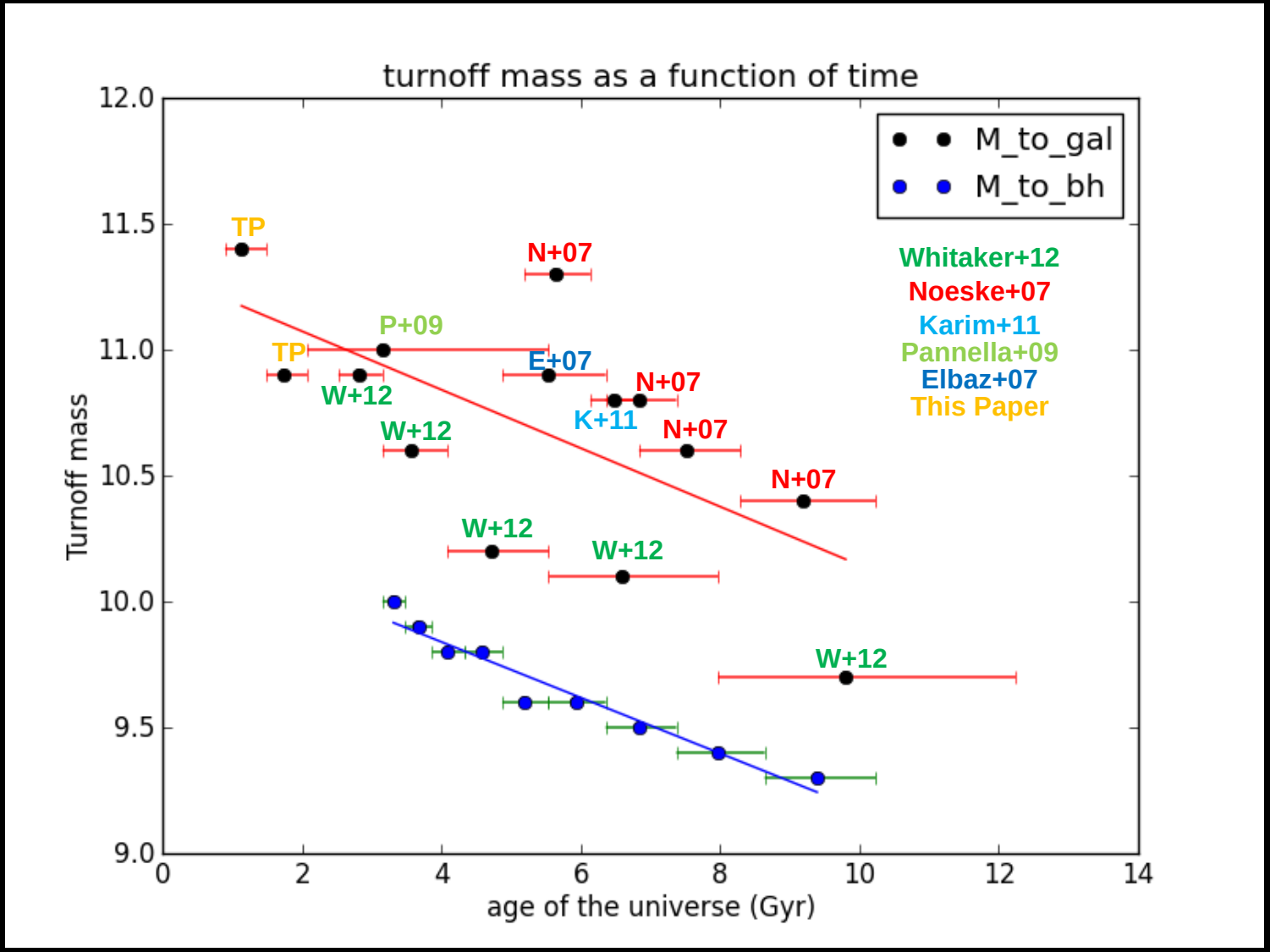


Comparing Time Evolutions

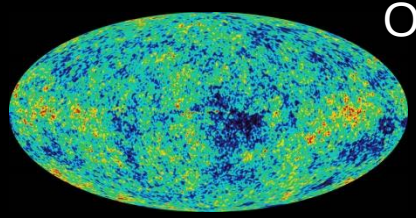
Time Evolution	Power Index	Normalization
MS Galaxies	.002*t*	-.193*t*
Quasars	.001*t*	-.179*t*

- Time evolution almost identical.
  - Only differs by a factor of ~1.5 (~.15-.2 dex) over the age of the universe.

MS vs. Quasars: Turnoff Masses



New Framework for Galaxy Evolution



Overdensities collapse

Mergers

Star formation

Star-forming galaxy

Supernovae go off

Gas travels to center

Gas powers AGN

AGN quenches SF

AGN shuts off

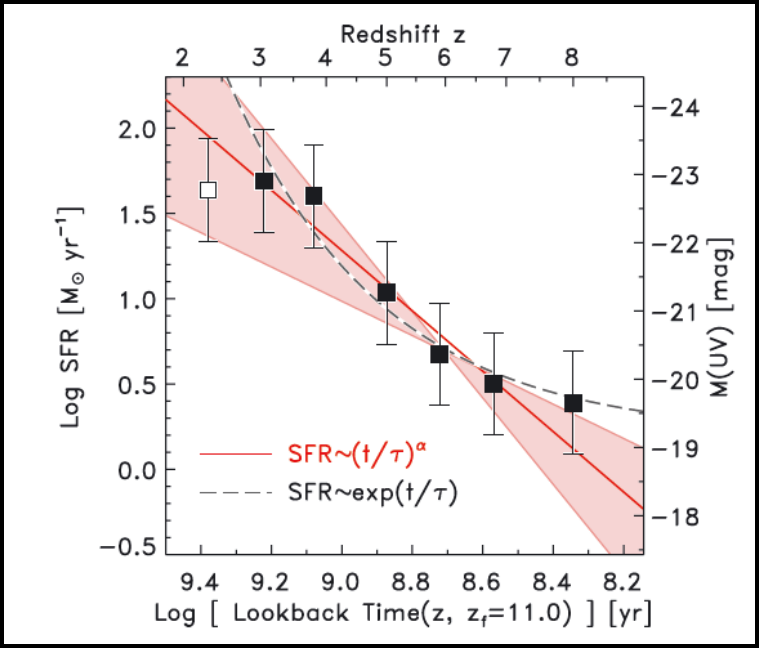
Quiescent galaxy

Some Predictions

- Star formation histories should be rising as a power law, not decaying in an exponential burst.
- Star formation triggers AGN activity that then quenches star formation, rather than major mergers.
- AGN should have long, quasi-continuous duty cycles.
- AGN activity should be delayed by $\sim \tau_{dyn}$ from the onset of SF.

Predictions: How Do They Fare?

- Star formation histories should be rising as a power law, not decaying in an exponential burst.
  - We find $SFR(t) \sim t^{1.3-2.8}$.
  - Papovich et al. (2011) uses UV luminosity functions and finds that $SFR(t) \sim t^{1.7\pm.2}$.



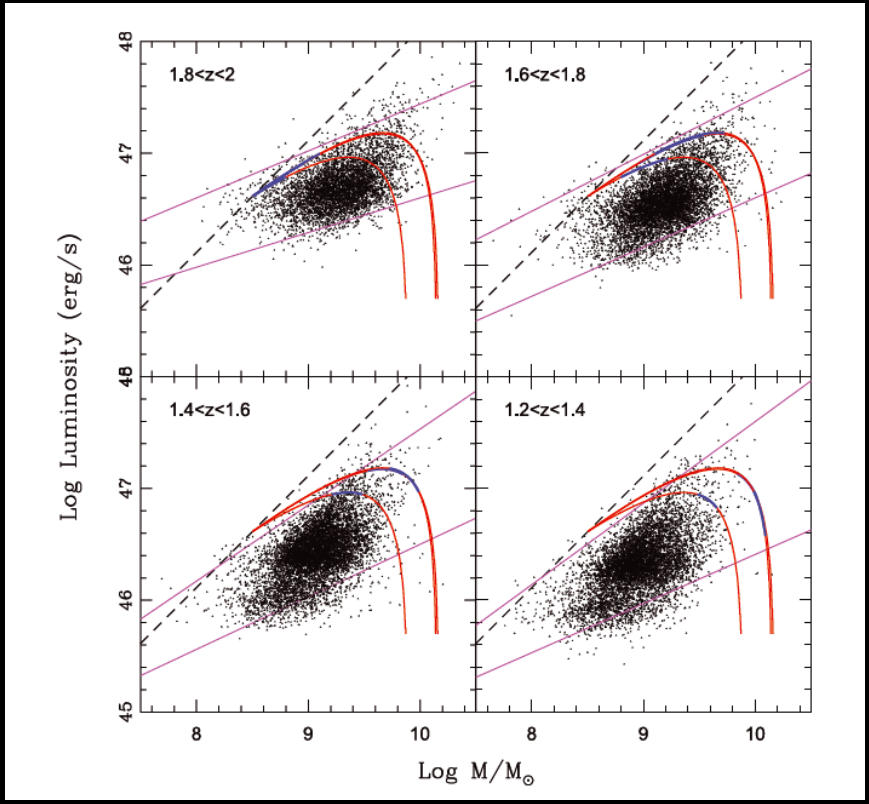
Taken from Papovich et al. (2011).

Predictions: How Do They Fare?

- Star formation triggers AGN activity that then quenches star formation, rather than major mergers.
  - Observations of star formation occurring during AGN activity (e.g. Daddi et al. 2007a,b).
  - AGN often are not the result of major mergers (e.g. Schawinski et al. 2012, Treister et al. 2012).
  - BH masses seem to be only weakly affected by merger history (e.g. Kulier et al. 2013).

Predictions: How Do They Fare?

- AGN should have long, quasi-continuous duty cycles.
  - Suggested by of Steinhardt, Elvis, & Amarie (2011).



Taken from Steinhardt, Elvis, & Amarie (2011).

Where to Go From Here?

- SPLASH data going to get better and better with HSC and more observing time so we can refine our analysis.
- Use the multiwavelength data to investigate dust evolution and other properties of galaxies at high redshift.
- Actually build the model proposed here and compare our results to those from simulations (e.g. Behroozi et al. 2013).
- Investigate whether the tight MS correlation is at odds with Press-Schechter.

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