Galaxy Formation and Evolution: Lecture 16:

The link between star formation and AGN activity

Course contents

1. Historical introduction
2. Challenges and recent advances
3. Galaxy formation in theory
4. Spectral synthesis and star formation indicators
5. The fossil record for local galaxies
6. Survey astronomy
7. The Madau Diagram and Lyman Break galaxies
8. Studying galaxy evolution in the IR/sub-mm
9. The evolution of early-type galaxies
10. Morphological evolution and spiral galaxies
11. AGN discovery and observed properties
12. AGNs and supermassive black holes
13. Black hole growth and formation
14. The triggering of AGN
15. AGN feedback and outflows
16. The link between star formation and AGN activity
17. The far frontier and outstanding challenges
18. The future of the Universe

By the end of this lecture:

You should have an understanding of:

- the evidence to support an AGN-SF connection;
- how we measure the AGN-SF connection;
- the star-forming Main Sequence;
- the importance of AGN variability;
- our current understanding.

AGN and Black Holes

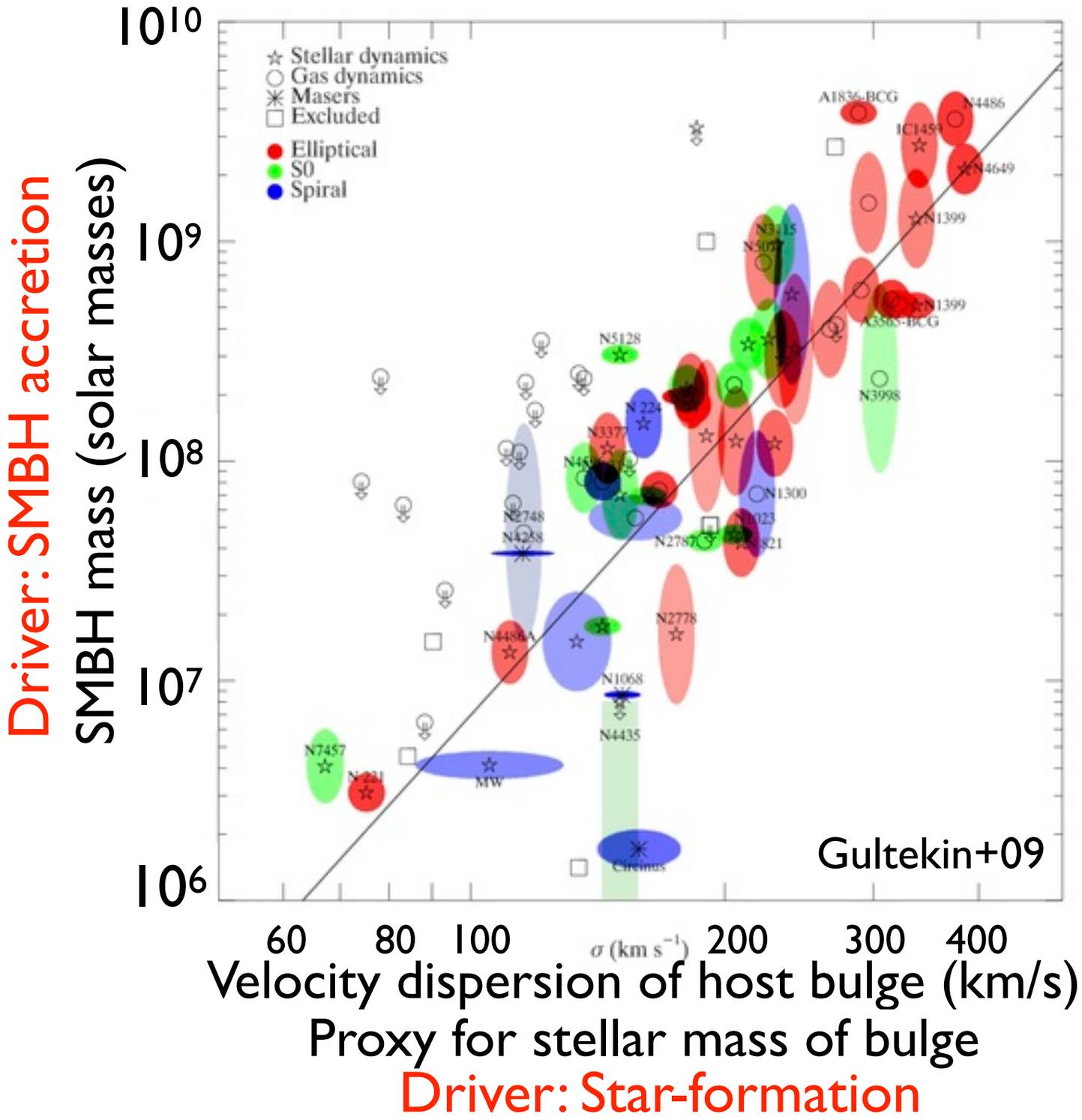
Quasars [powerful AGN] are the result of interstellar material (i.e., gas & dust) accreting onto central, supermassive black holes.

Consequently, these are sites of supermassive black hole growth at the centres of galaxies.

A black hole's mass is the sum of all previous accretion events.

Lynden-Bell 1969

Black hole/bulge mass



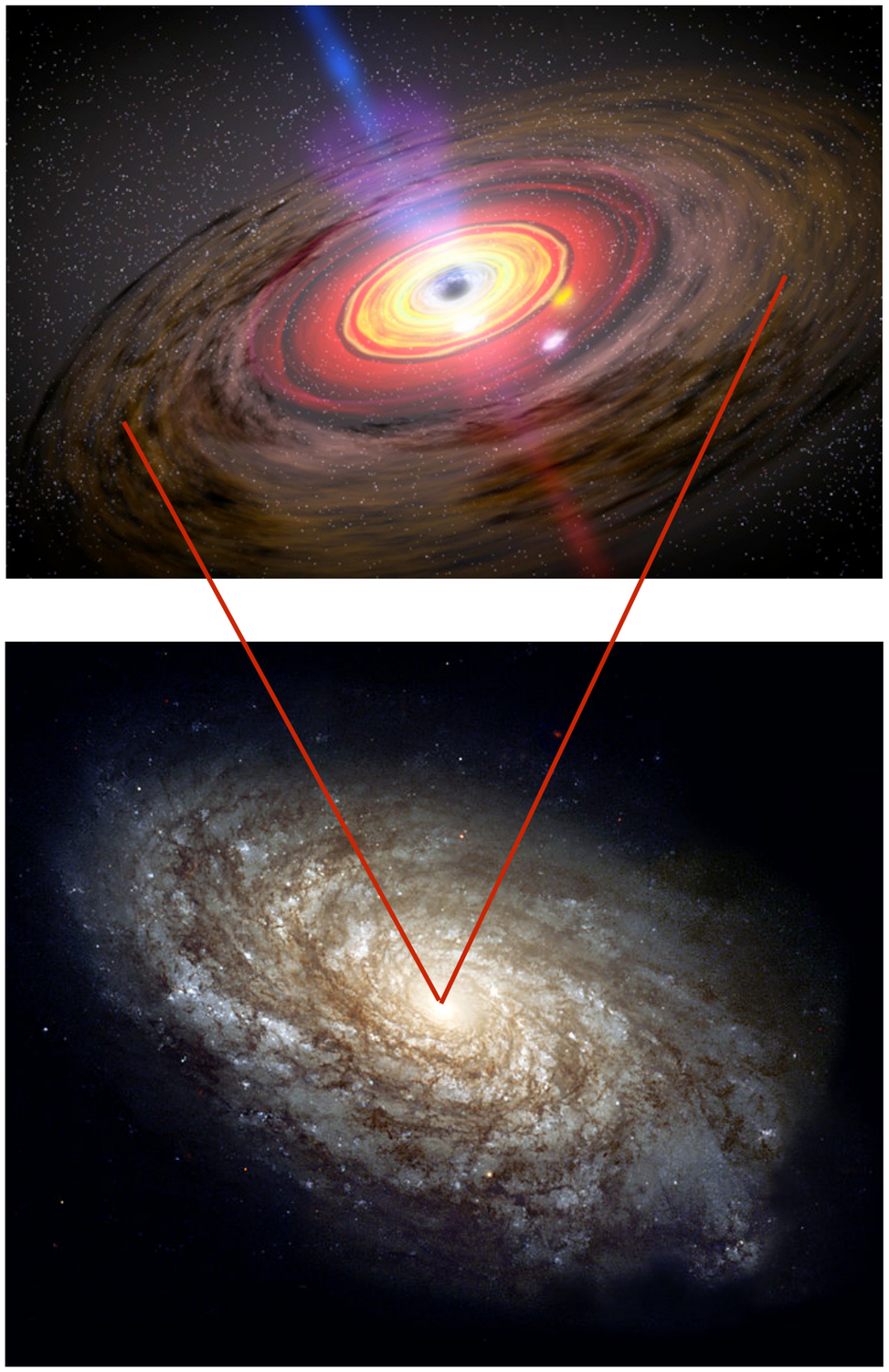
BH mass now known to scale with the stellar mass of the bulges of their host galaxies.

There is a strong desire to understand how this has come about.

Telling us something important about how galaxies and BHs grow together?

(also, Magorrian+98, Gebhardt+00, McLure+02, Marconi+Hunt 03, Haring+Rix 04, Gultekin+09, Kormendy+11, Bennert+11, etc)

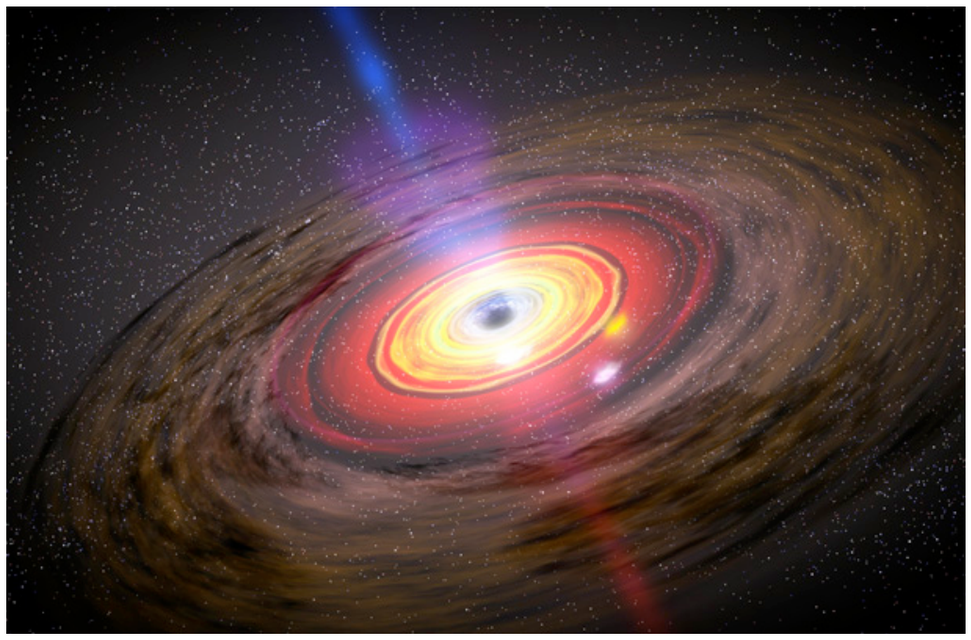
Black hole/bulge mass



One key way of doing this is to measure the star-forming properties of galaxies hosting growing BHs (i.e., AGN).

In doing so, we measure the build-up of stellar and BH mass.

Measuring BH growth



AGN luminosity is assumed to be proportional to BH growth:

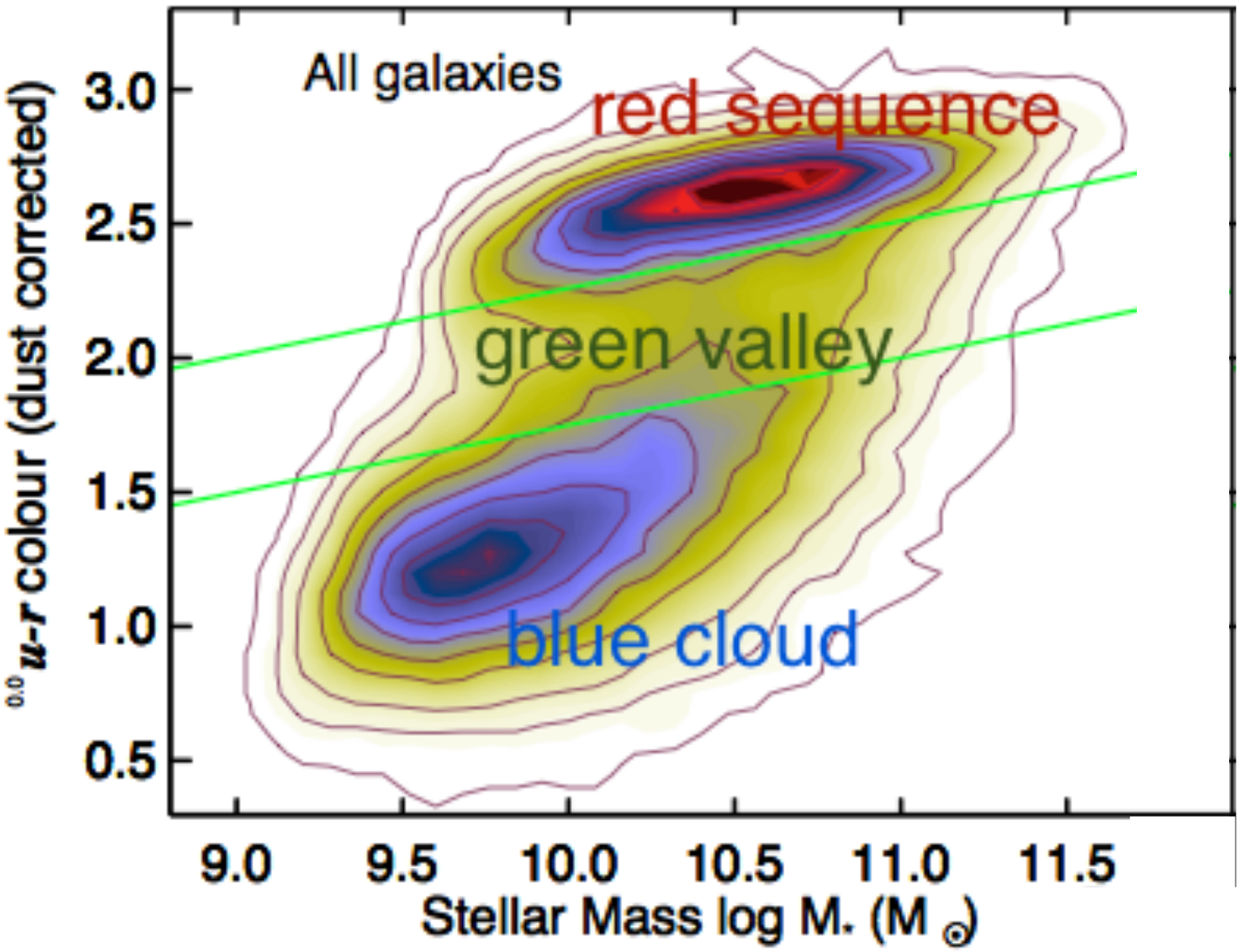
$$L_{\mathrm{AGN}} = \eta \dot{M}_{\mathrm{BH}} c^2$$

Measuring star-formation

Different ways to measure ongoing star-formation rates.
They're all essentially a measure of young, hot stars, e.g.,:

- UV continuum (direct);
- galaxy colour (bluer: more star-forming)
- Hα, [O II], …, emission lines (gas ionised by host stars);
- infrared continuum (hot dust, heated by hot stars).

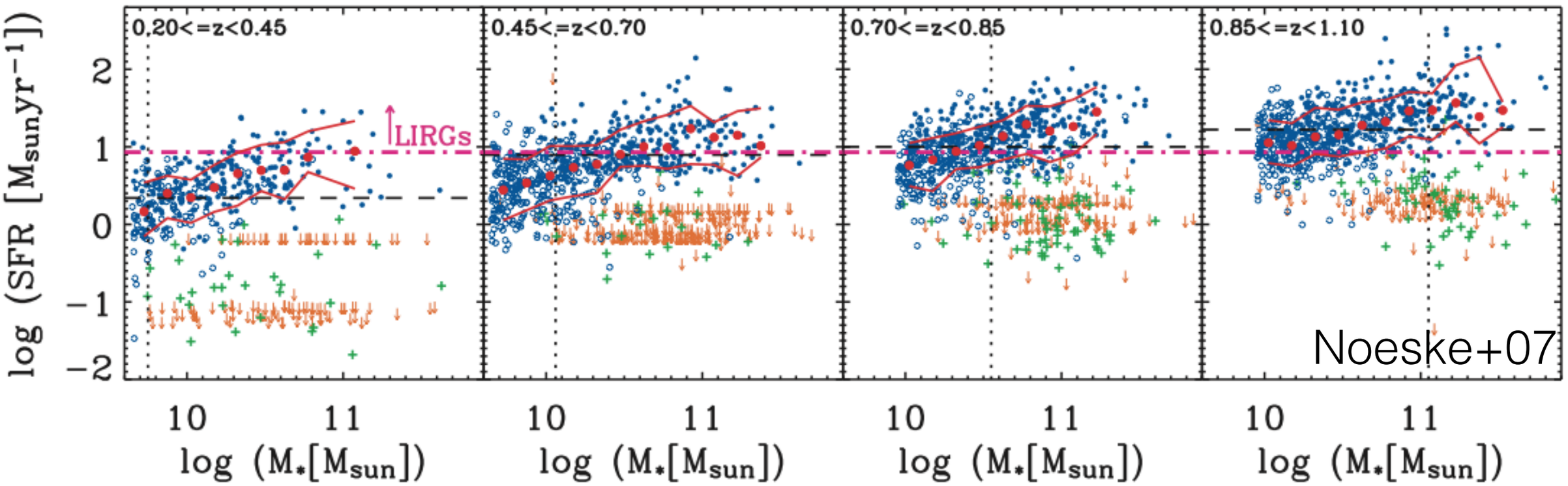
Star-forming galaxies



At a given stellar mass, the galaxy population is bi-modal. They split into:

- blue, star-forming galaxies;
- red, “dead” galaxies.

Star-forming Main Sequence

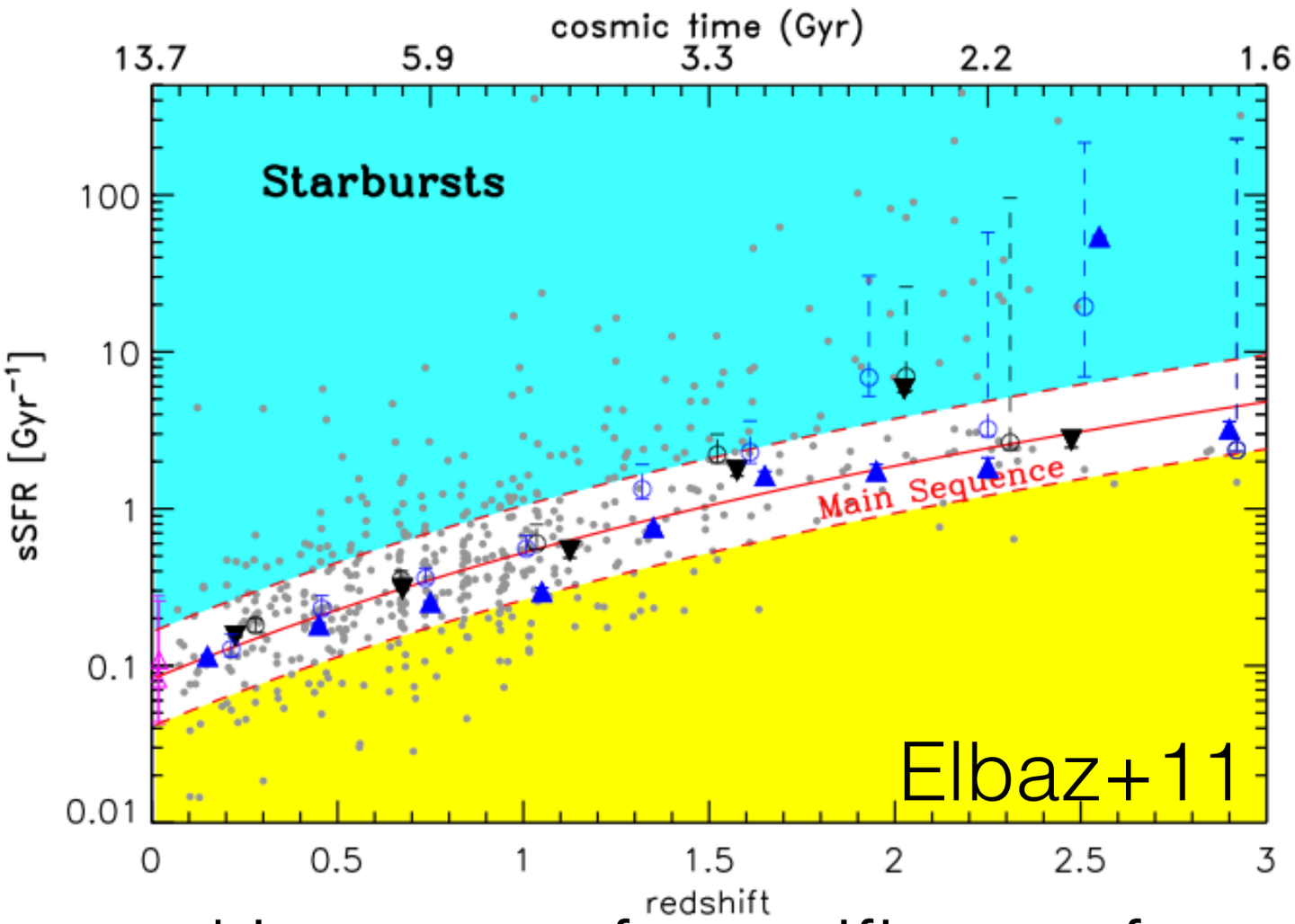


When we select the star-forming population, we find that their star-formation rates correlate with stellar mass.

This has become known as the galaxy (or sometimes the star-forming) **Main Sequence**.

It has nothing to do with the stellar main sequence (i.e., from the H-R diagram).

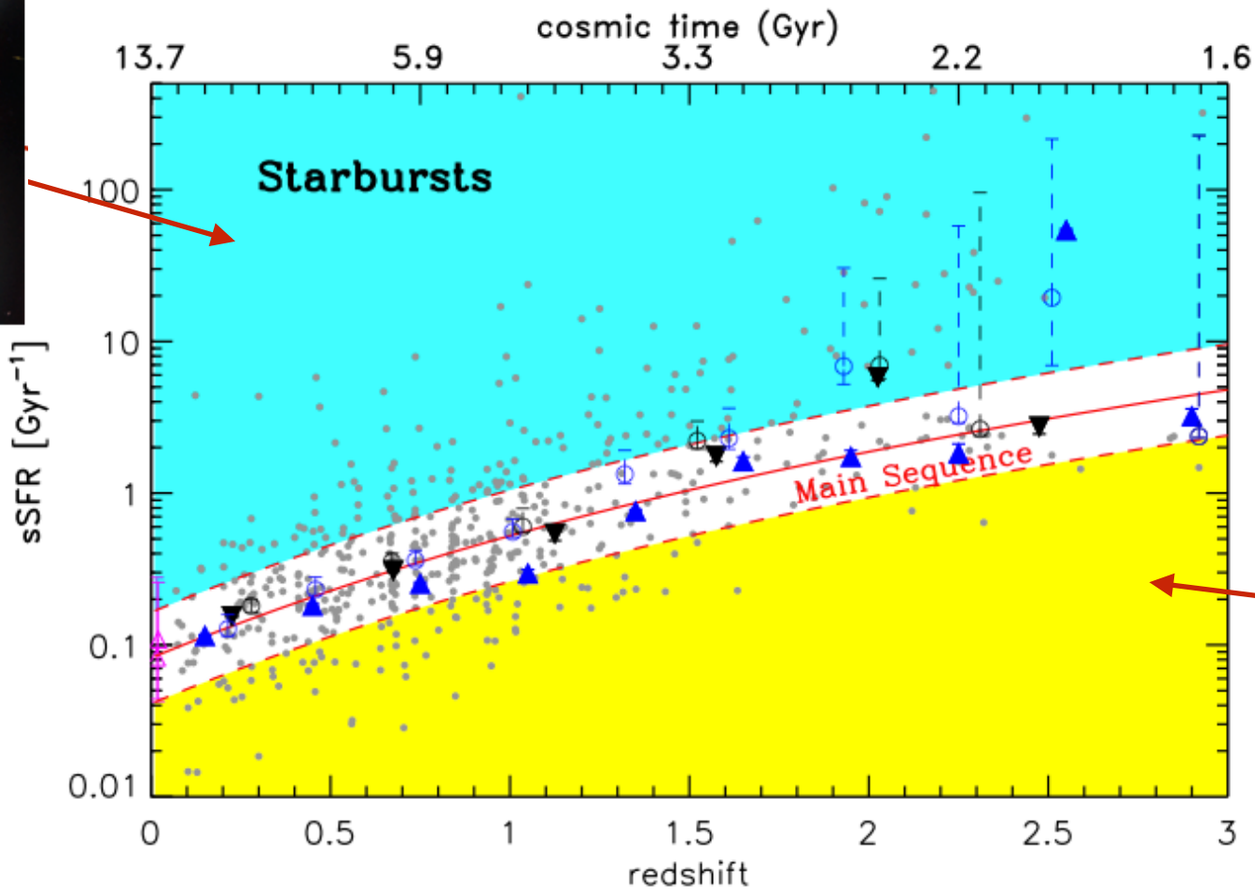
Redshift evolution of MS



- Often expressed in terms of specific star formation rate: sSFR = SFR/stellar mass
- Galaxies with sSFRs above the Main Sequence are known as “Starbursts”.
- The average sSFR of Main Sequence galaxies increases with redshift.

Main Sequence vs Starbursts

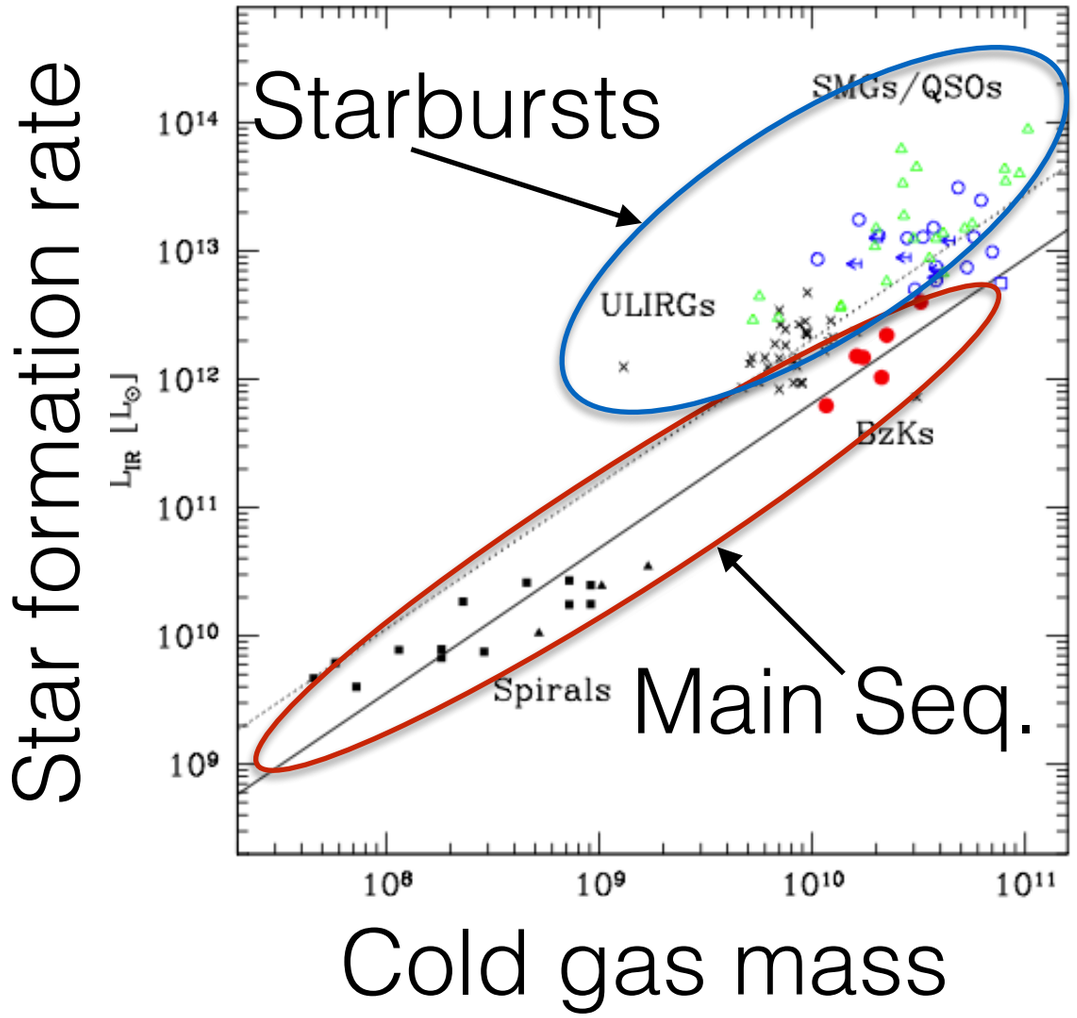
Starbursts have been found to often be associated with major-merging galaxies.

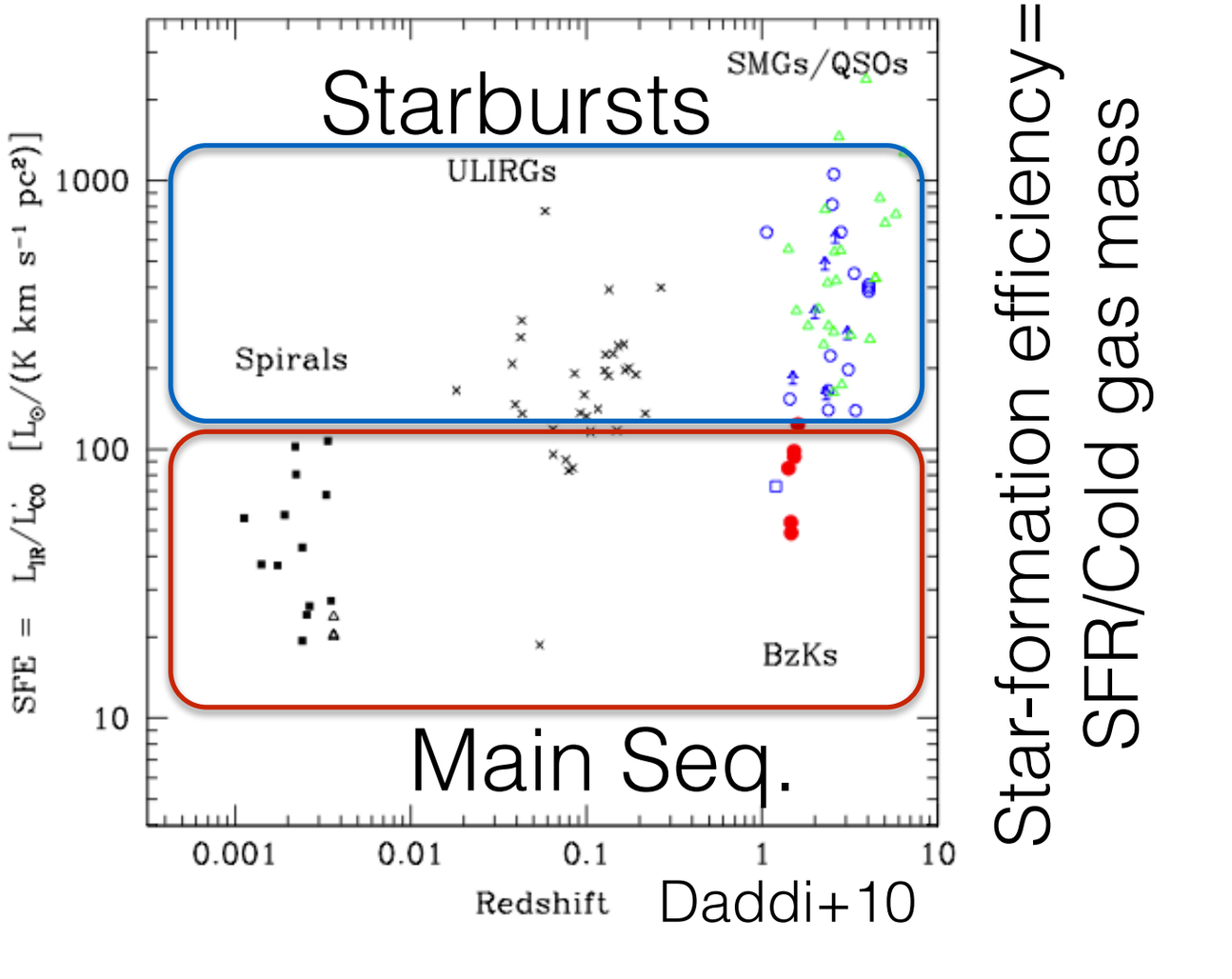


Main Sequence galaxies are more commonly associated with non-merging galaxies.

The dominant mode of star-formation in the Universe IS NOT triggered by major-merging galaxies.

Why the rise in sSFR?





Main Sequence galaxies have higher gas masses at high redshifts.
But, their star-formation rate per unit gas mass stays roughly constant.

→ The reason why their sSFR increase with redshift is that there is more cold gas in the high-z Universe to form stars with.

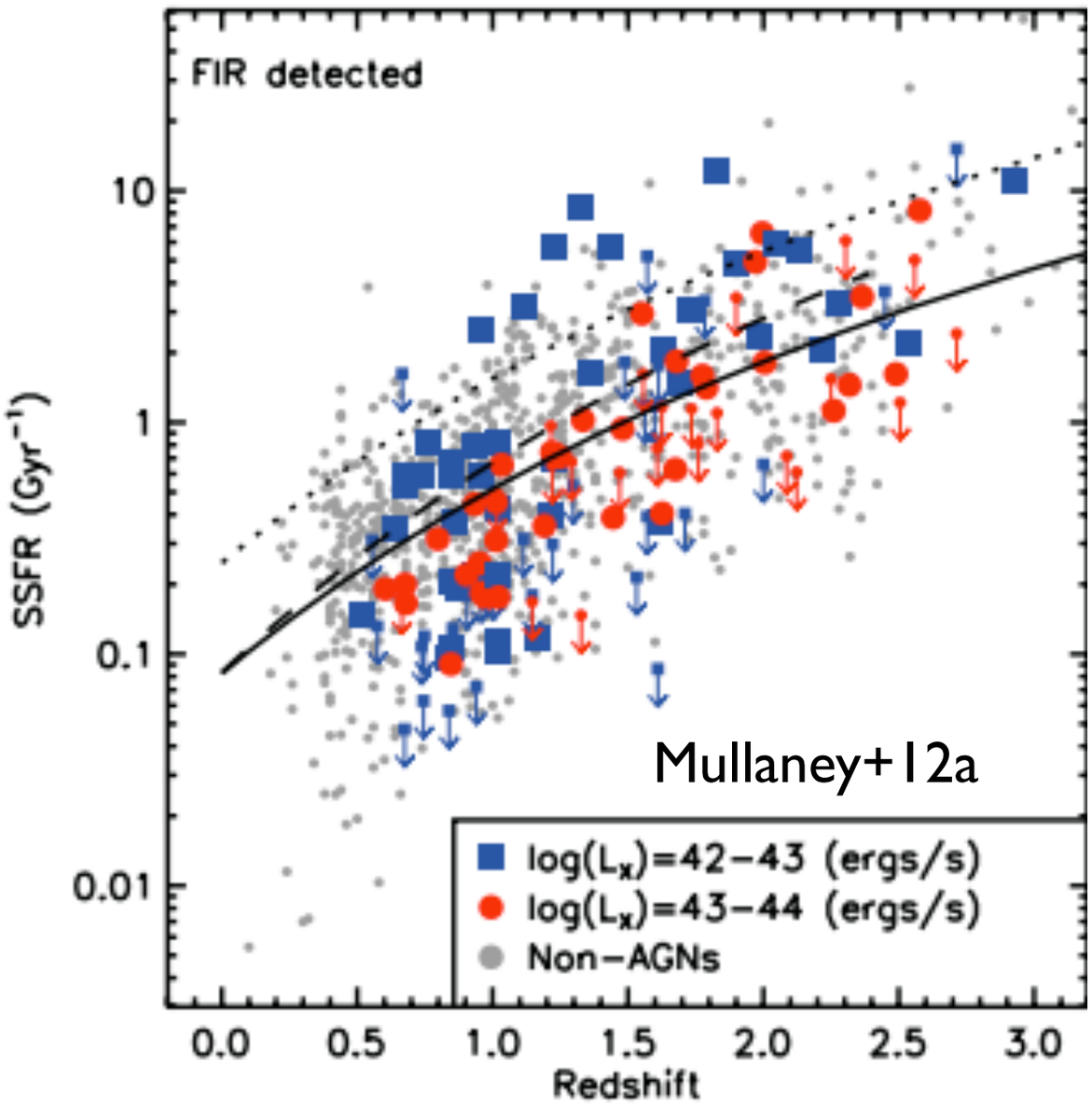
Daddi+10, Genzel+10

Main Sequence Summary

Key points to remember:

- At a given redshift, galaxies on the **Main Sequence** (MS) have star-formation rates (SFRs) that are proportional to their stellar mass.
- So, at a given redshift, their specific SFRs (sSFR=SFR/stellar mass) is constant (but with some scatter).
- Galaxies with sSFRs ~3x above the MS are known as **Starbursts** (SBs)**.**
- Star-formation in MS galaxies is thought to be triggered by “secular” processes, (e.g., disk instabilities), whereas in SBs it is triggered by major mergers.
- But, SBs are comparatively rare, so MS galaxies dominate the star-formation budget.
- The average sSFR of MS galaxies increases strongly with redshift.
- This redshift evolution is thought to be due to the greater availability of cold gas in the early Universe from which to form stars.

AGN and the Main Sequence

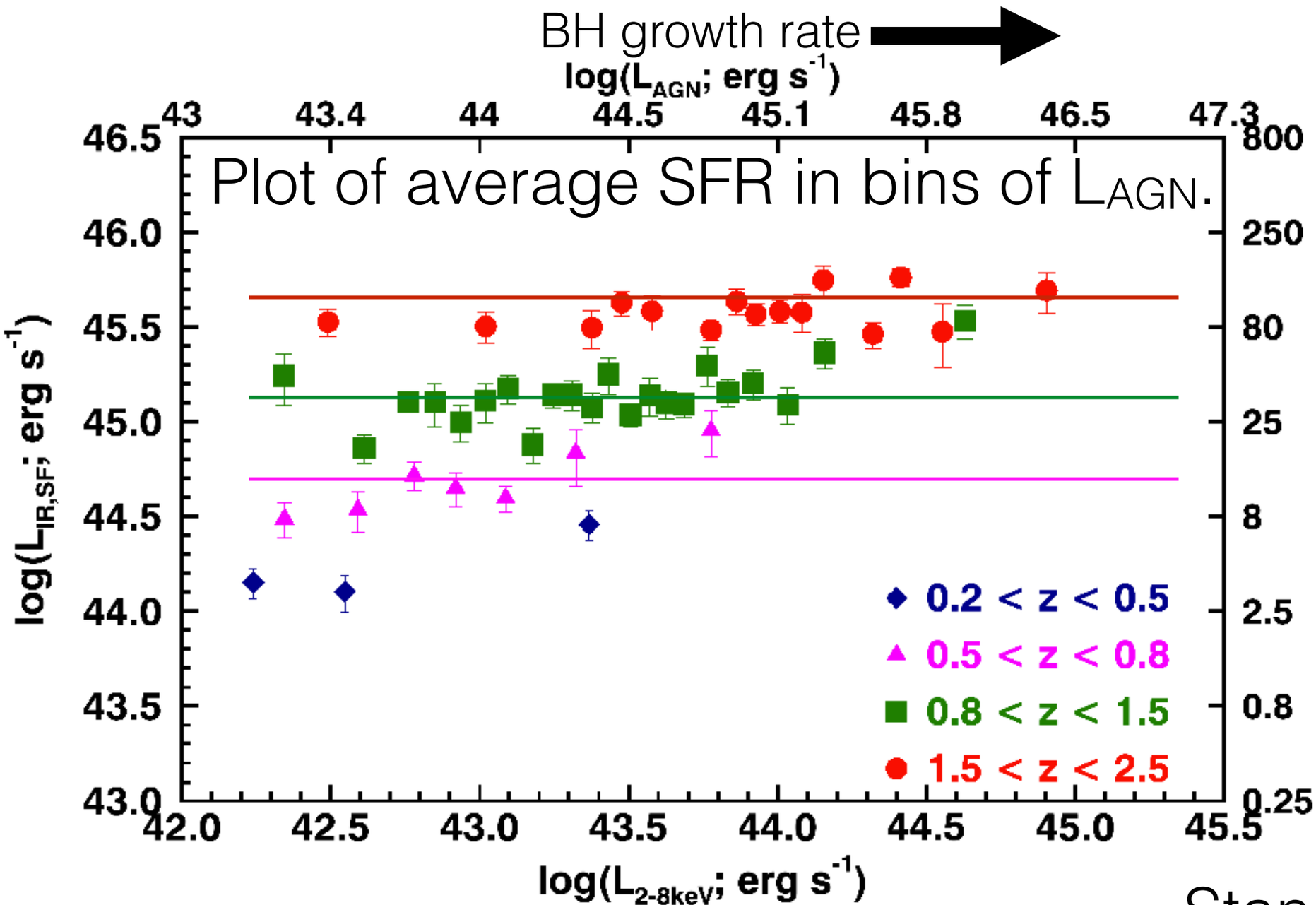


When we measure the sSFR of galaxies hosting AGN (i.e., growing BHs), we find that they are broadly consistent with Main Sequence galaxies.

In other words, AGN preferentially reside in main sequence galaxies.

BH growth — Star-formation correlation?

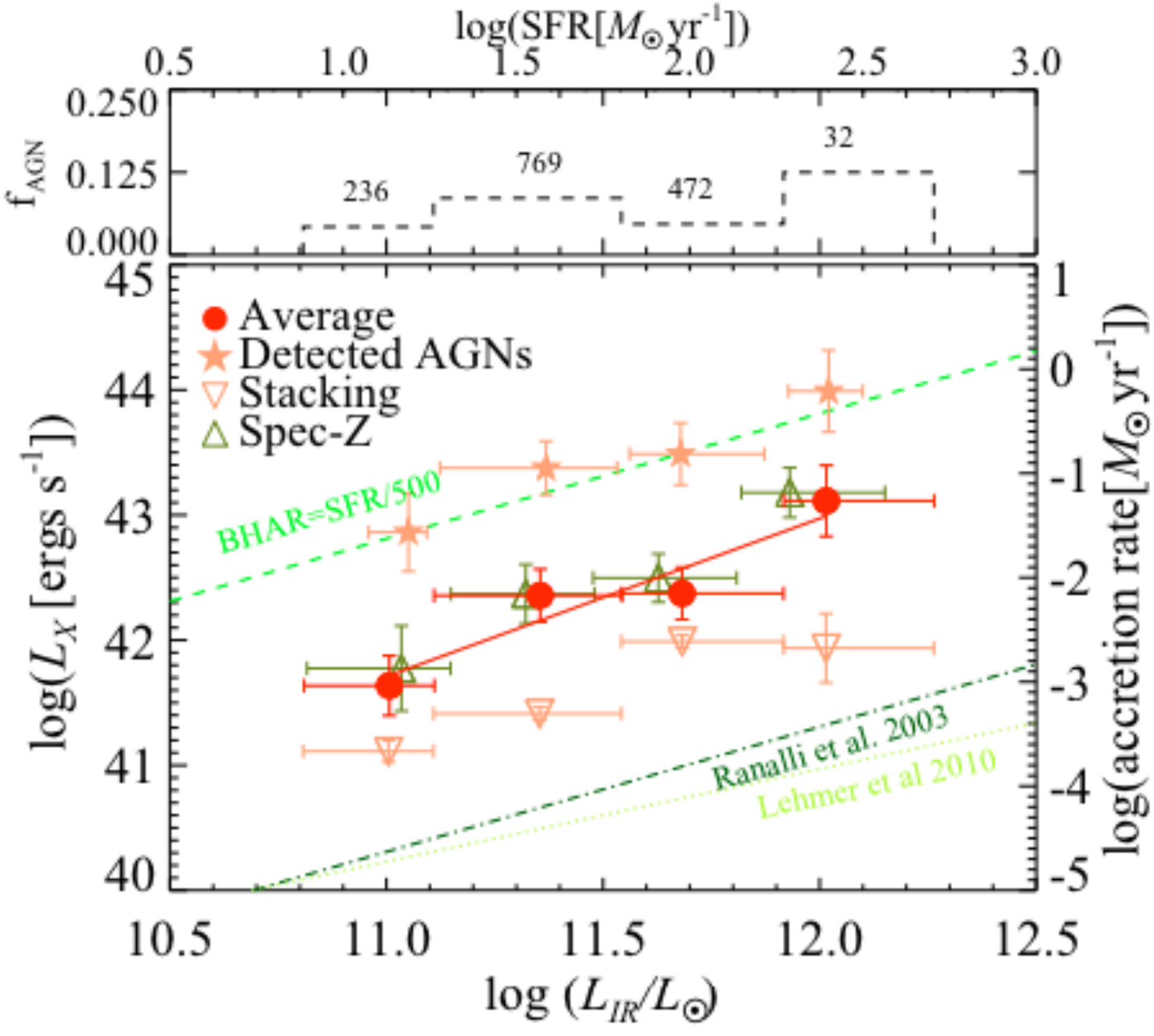
So, if BH growth preferentially takes place in star-forming galaxies, do we see a connection between BH growth *rate* and star formation *rate*?



Stanley+2015

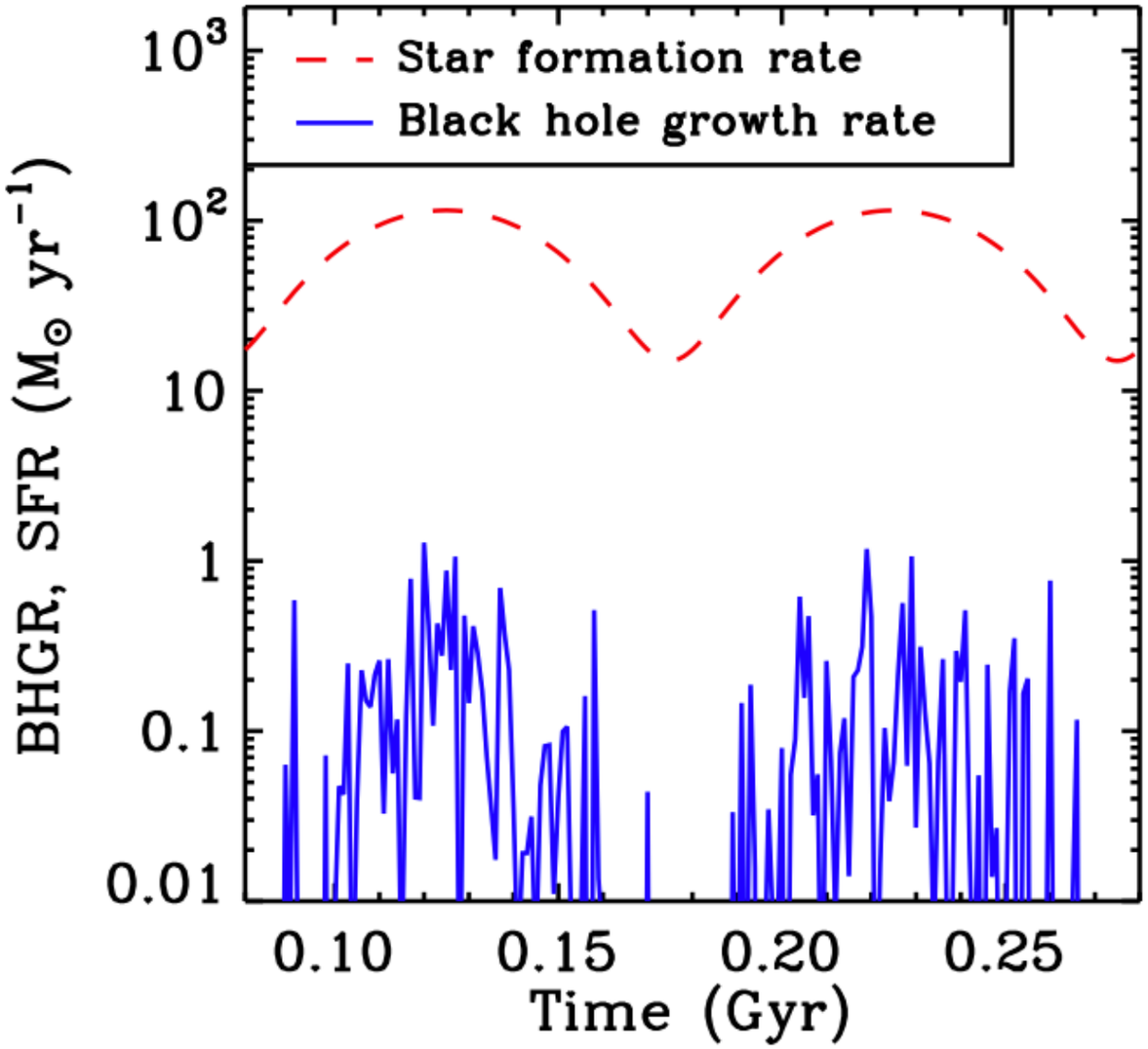
BH growth — Star-formation correlation?

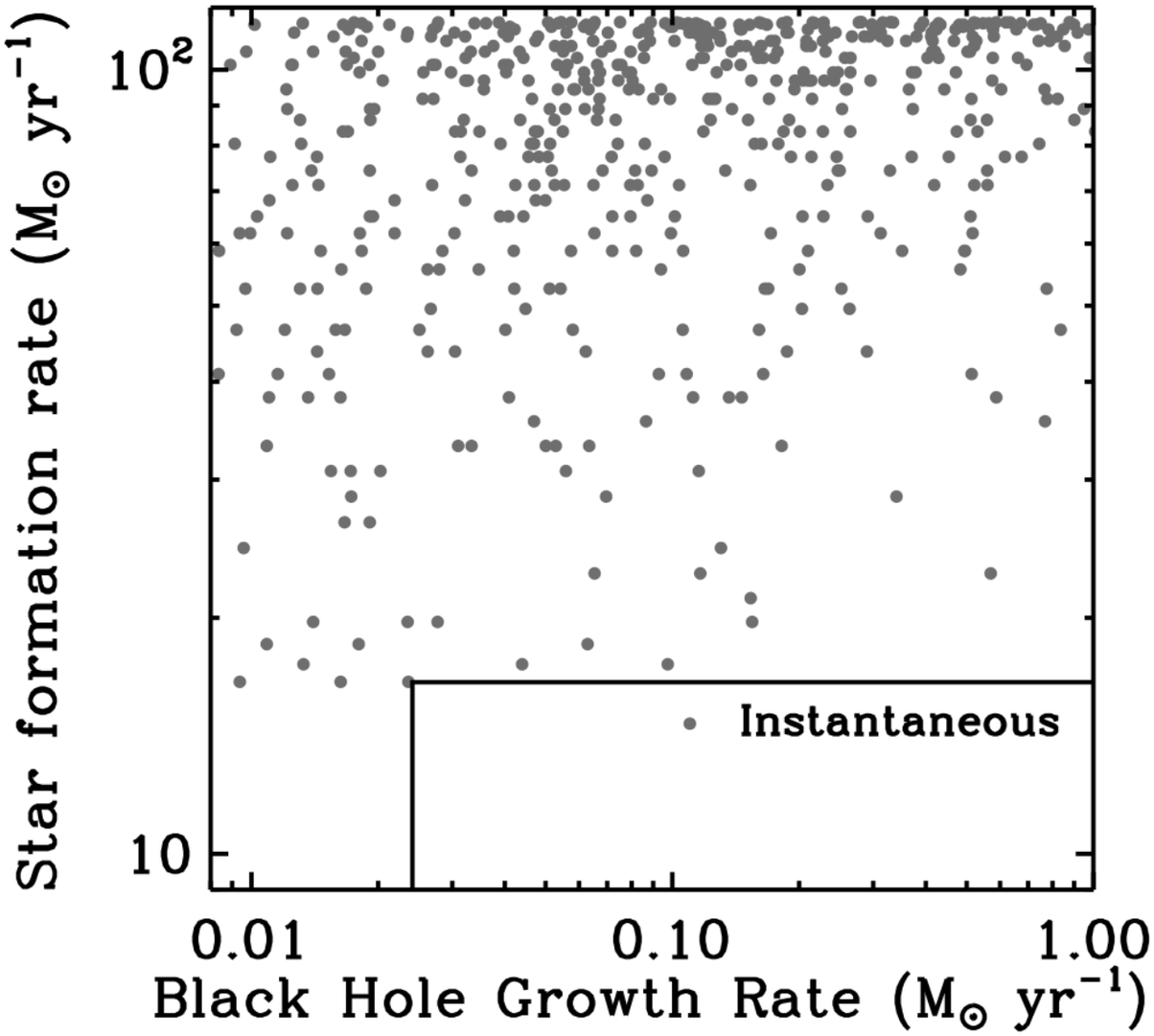
But, if we instead measure the average BH growth rate in galaxies binned according to star-formation rate, we do see a correlation. What's going on???



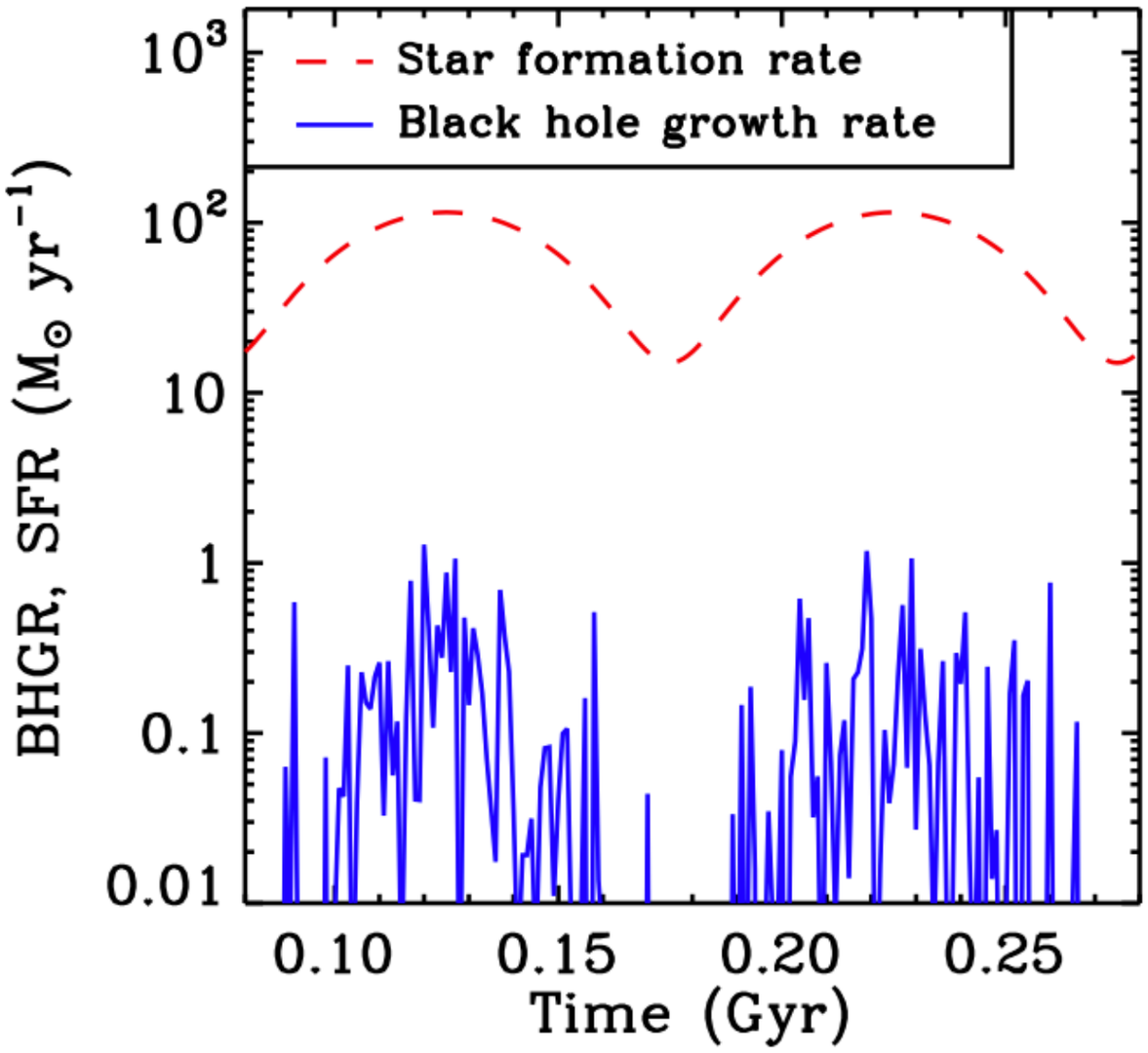
Chen+2013

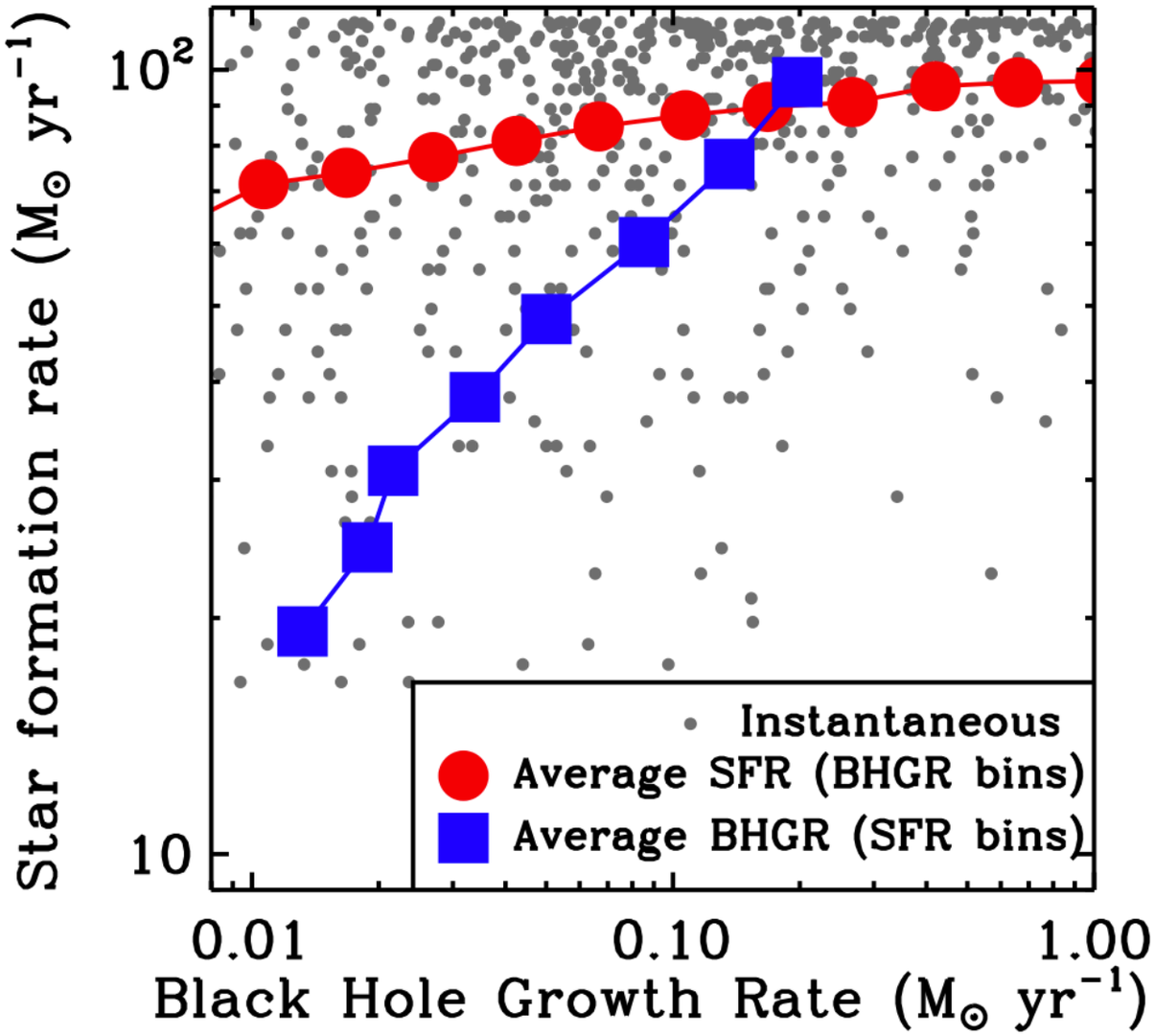
The importance of variability





The importance of variability





Black hole growth is a rapidly varying, stochastic process compared to star-formation, so we need to be careful when we are comparing them.

The probability of BH growth

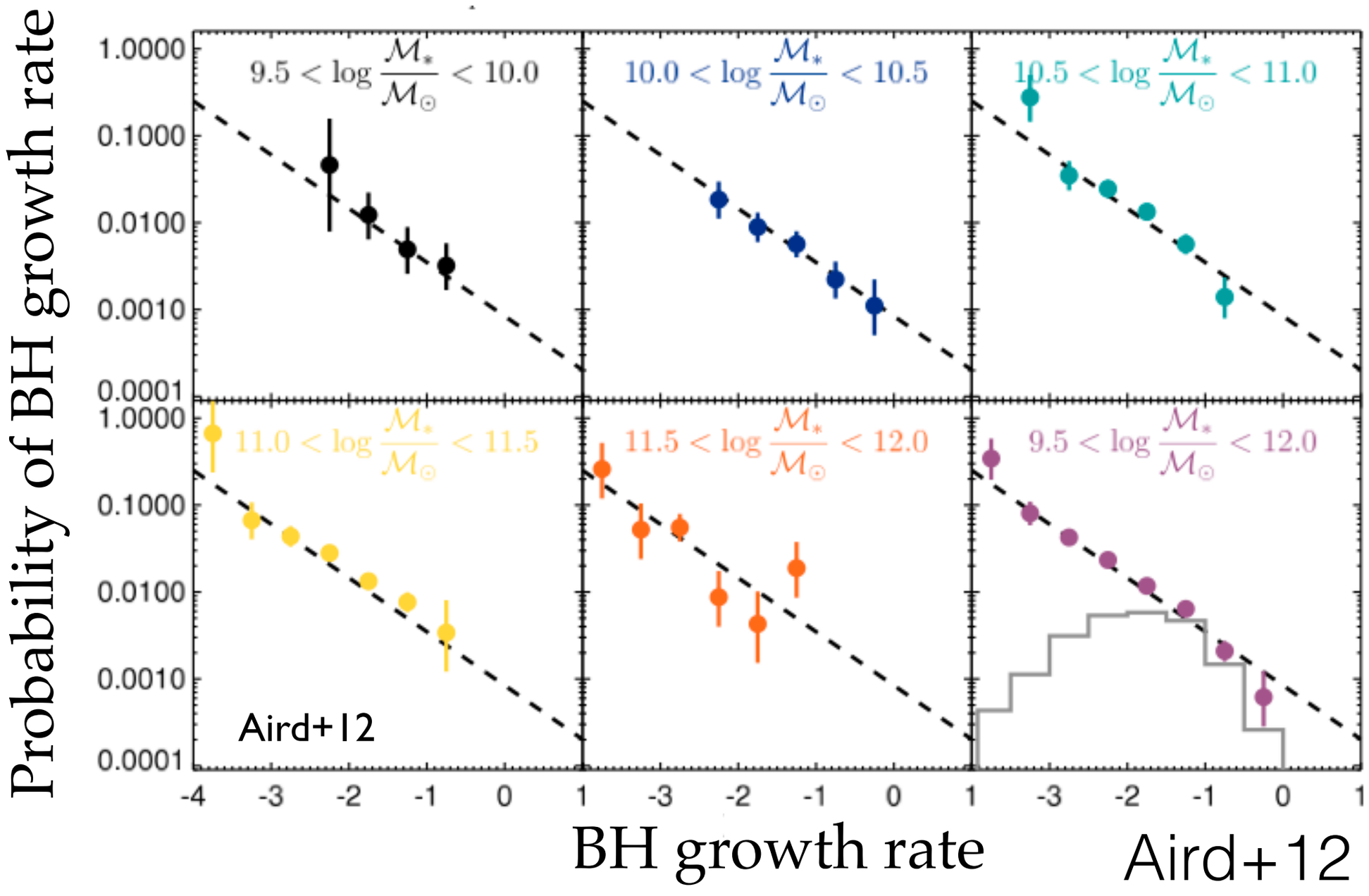
For variable, stochastic processes, it can be useful to think in terms of probability.

For example: “There’s a 80% chance or rain today”.

Recently, some astronomers have started to think about BH growth in the same way.

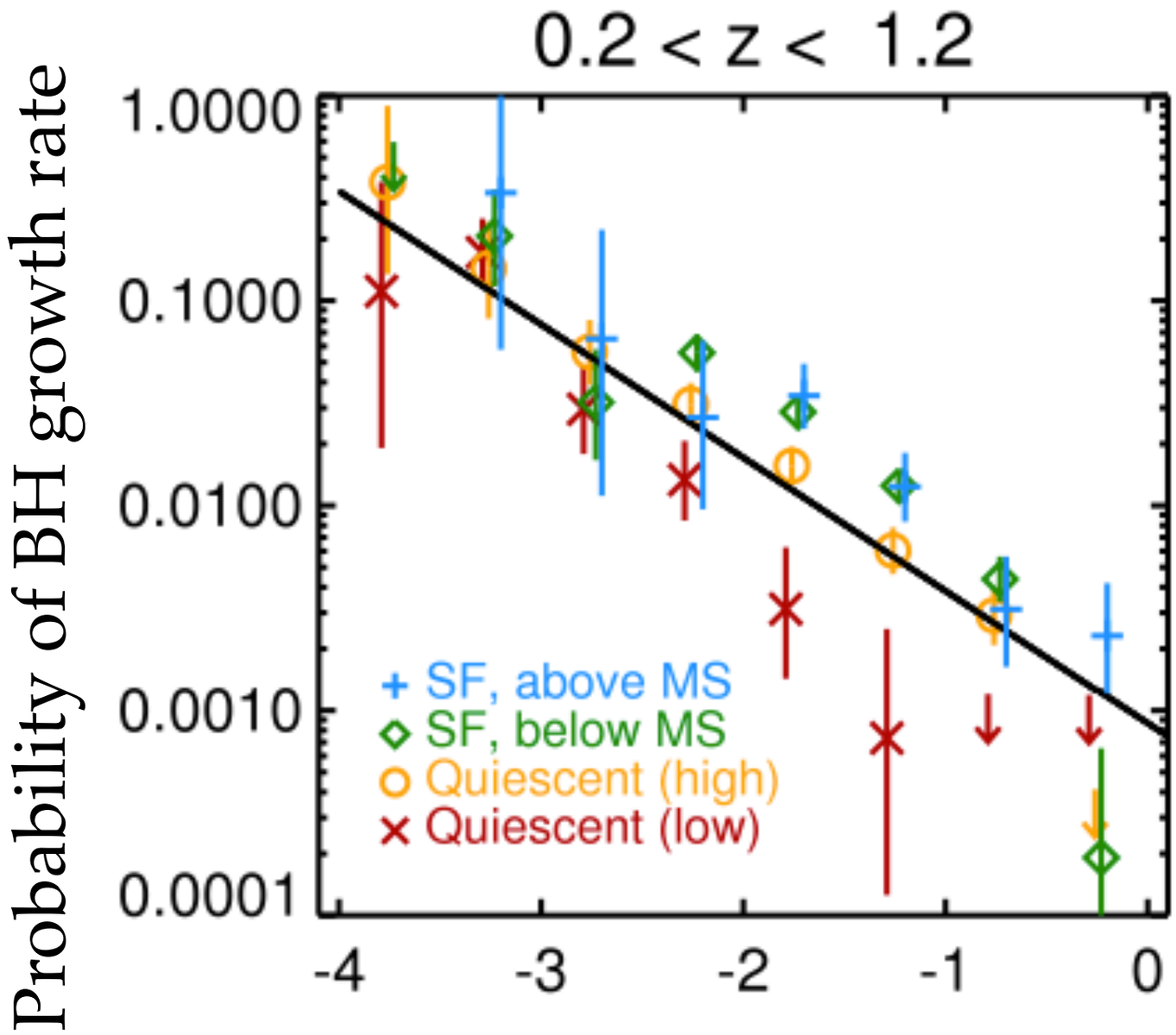
The probability of BH growth

Go beyond considering the probability of BH growth, to instead consider the probability of a given BH growth *rate*.



The probability of BH growth

Recent studies have found that the probability of rapid BH growth is higher in star-forming galaxies.



Azadi+ 2014

By the end of this lecture:

You should have an understanding of:

- the evidence to support an AGN-SF connection;
  - BH-bulge relationship.
- how we measure the AGN-SF connection;
  - L_{AGN} (X-rays, etc), SFR (IR, Optical etc)
- the star-forming Main Sequence;
  - sSFR rises with redshift due to the increased availability of gas in the early Universe.
- the importance of AGN variability;
  - “Washes out” the underlying connections
- our current understanding.
  - rapid BH growth is more *prevalent* in star-forming galaxies.