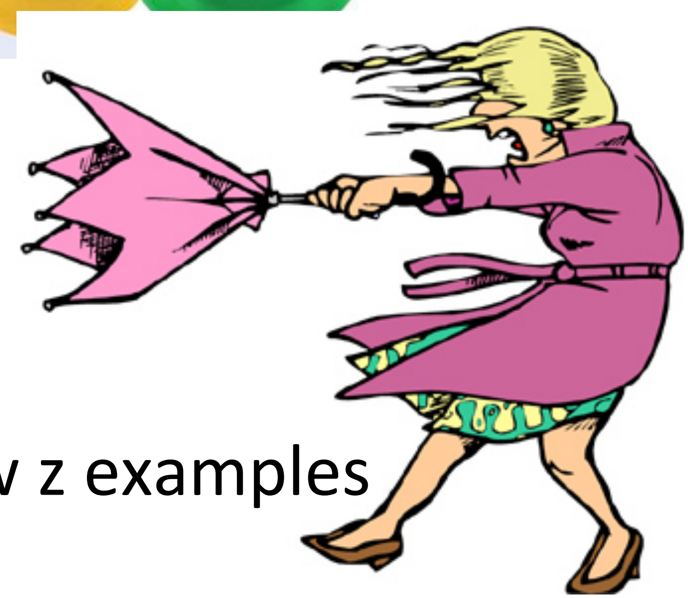
ועכשיו למשהו שונה לגמרי

Evidence For Feedback

A highly biased review

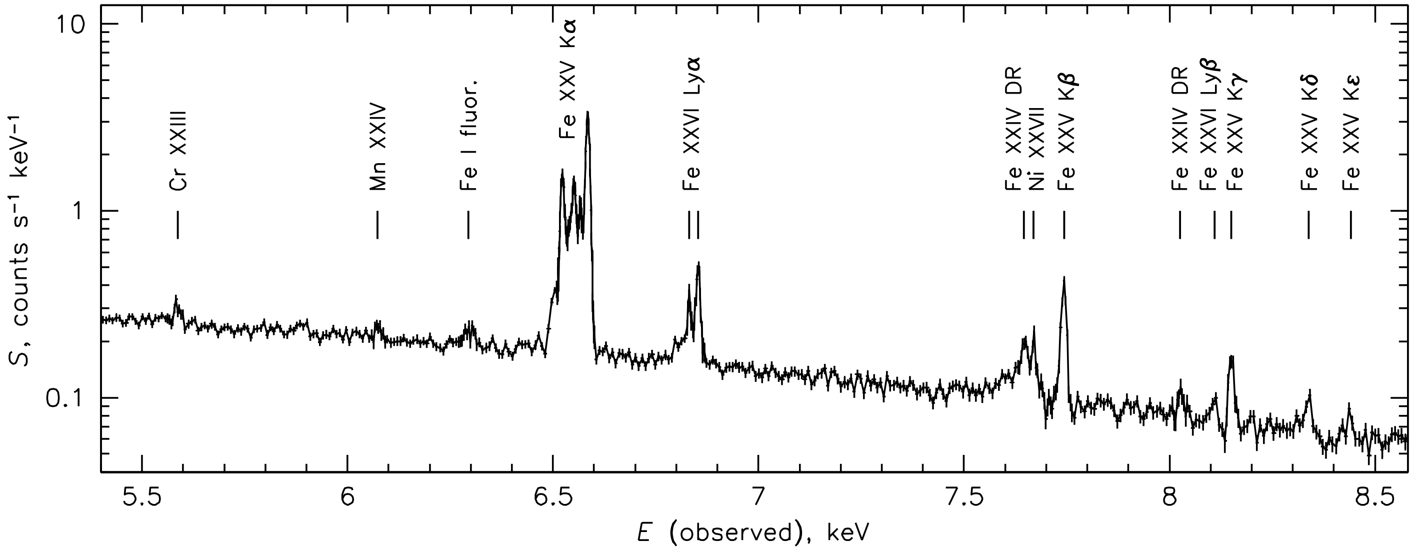
Jets, Winds, Disks and Their Interaction

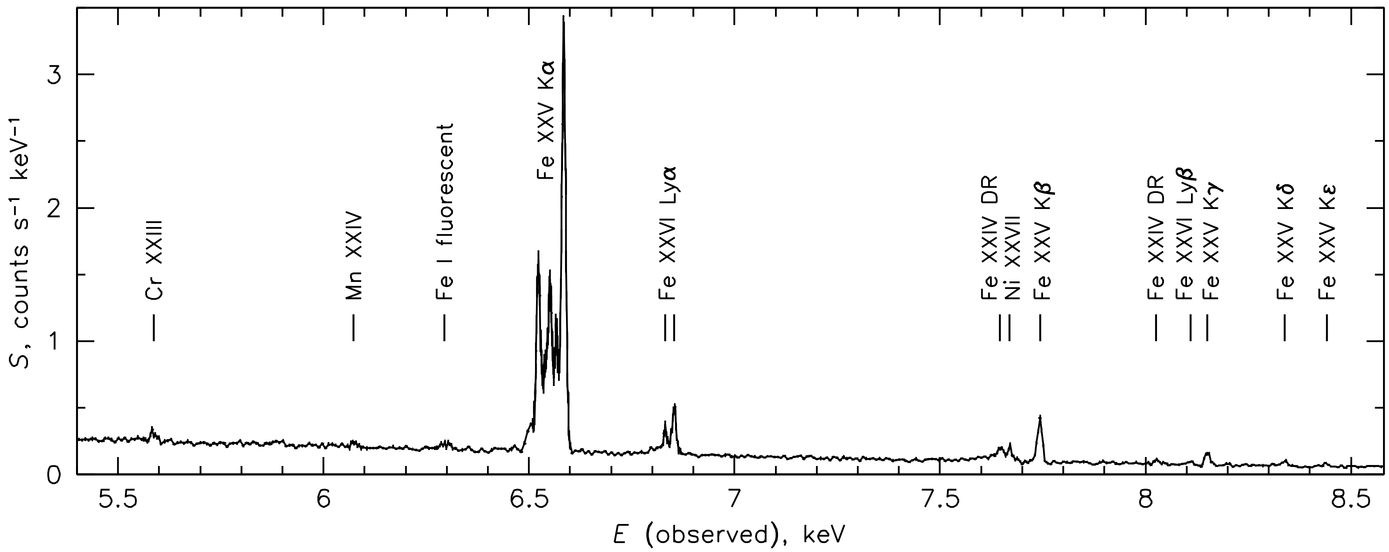


Low z examples

Very popular field- over1200 papers in last 10 years on this subject-

Hitomi SXS Data for Perseus Cluster

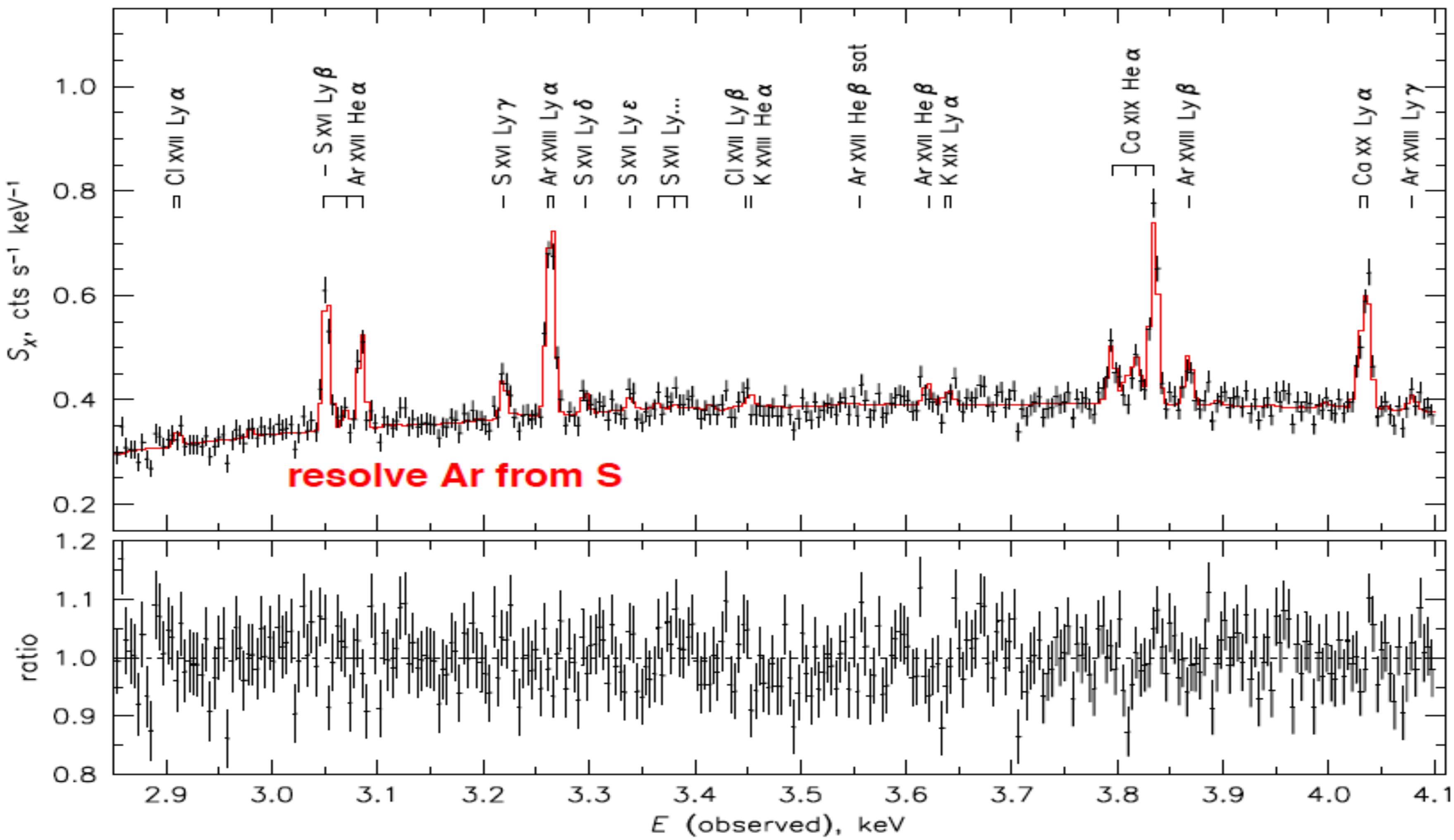


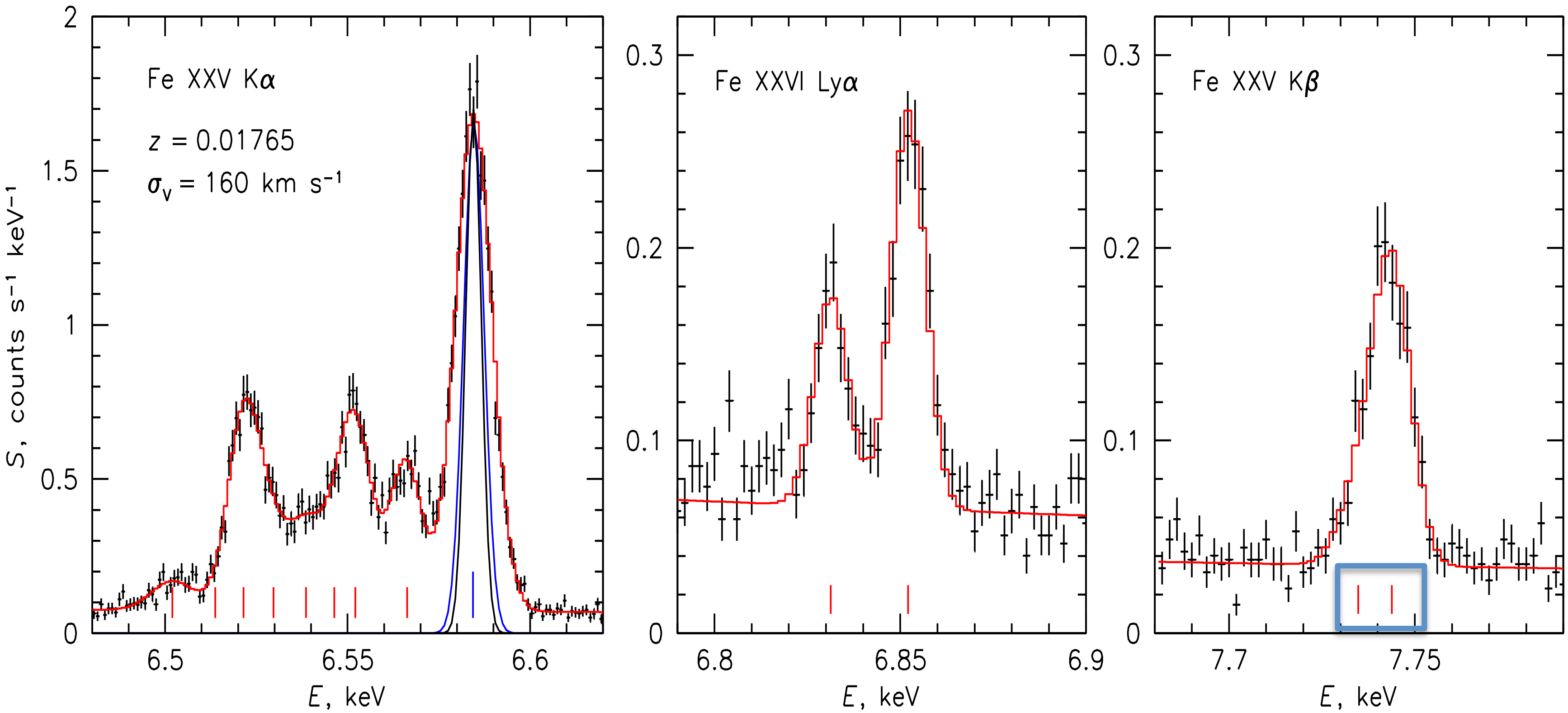


Full array

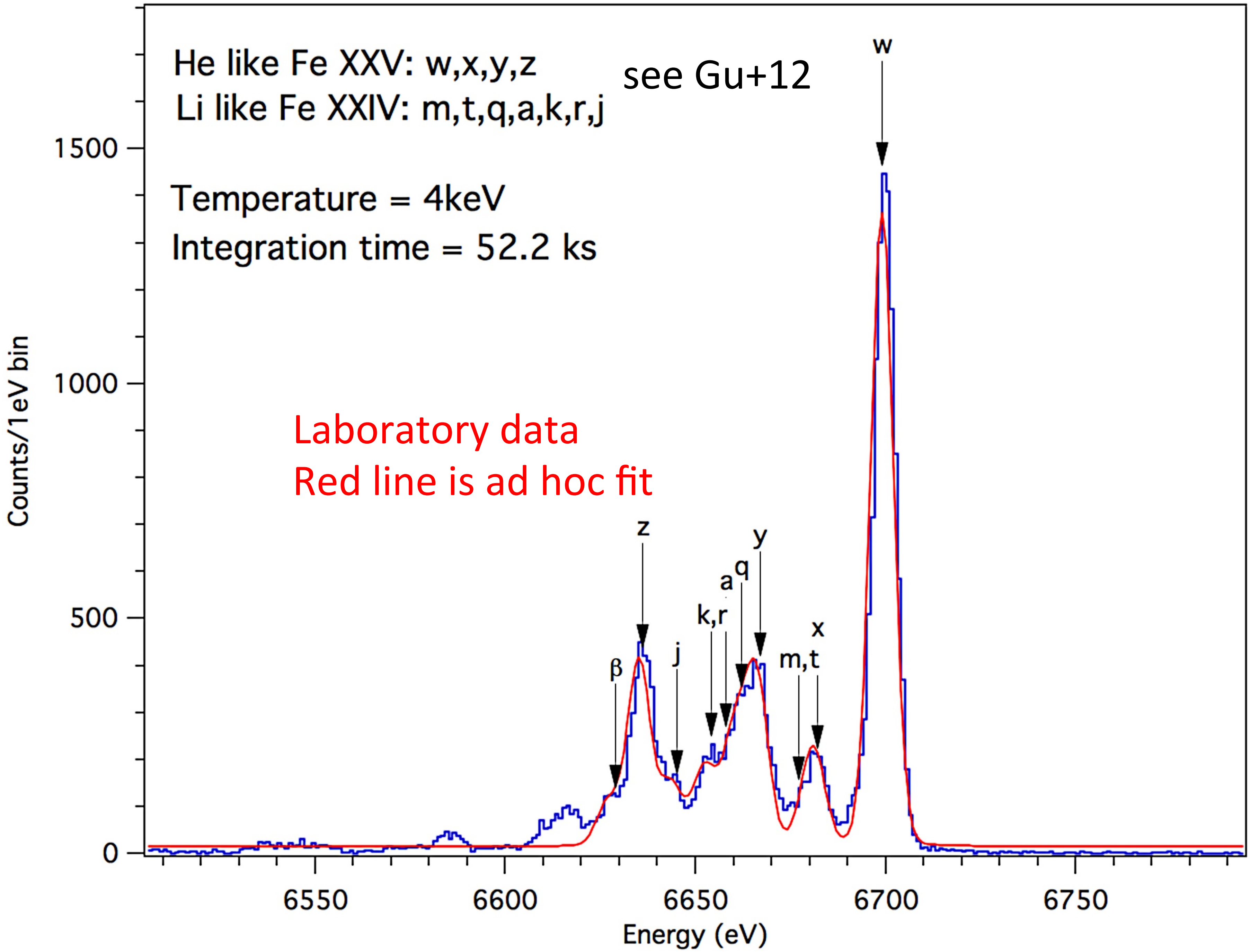
Chemical Abundances

Hitomi has the possibility to produce extremely precise chemical abundances which allow constraints on how many supernova occurred in the cluster and the types of supernova





Determine line widths, σ, using Gaussians fitted at lab energies



He like Fe XXV: w,x,y,z
Li like Fe XXIV: m,t,q,a,k,r,j
see Gu+12
Temperature = 4keV
Integration time = 52.2 ks
Laboratory data
Red line is ad hoc fit
w
z
y
a
q
k,r
x
j
β
m,t
0
500
1000
1500
6550
6600
6650
6700
6750
Counts/1eV bin
Energy (eV)

The Star-Forming Properties of an Ultra-Hard X-ray Selected Sample of AGN

Richard Mushotzky, Marcio Melendez, Mike Koss, Amy Barger, Len Cowie

Krista Smith

Is there evidence for feedback in AGN host galaxies? **YES**

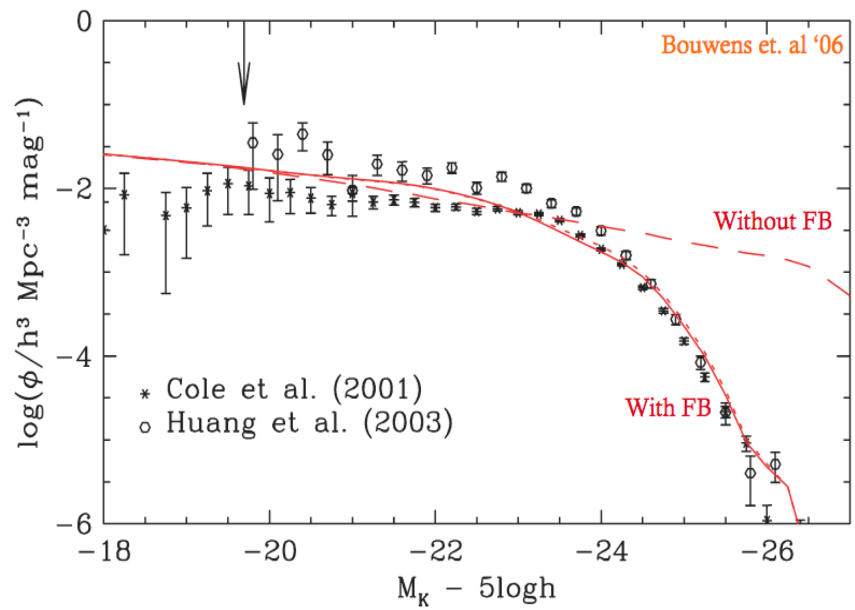
Is star formation in AGN hosts different from normal galaxies? **Somewhat**

Taro Shimizu

A Reminder

- A large number of theoretical calculations (Somerville and Dave 2015) have indicated that AGN feedback in massive galaxies ($M>M_*$) is necessary to
  - produce the right number of massive galaxies at z=0
  - produce the correct color, mass and number evolution over cosmic time (z<3)
  - and lots of other things
    - simulations indicate massive systems at high redshifts are weakly affected by AGN activity.

AGN Feedback



Luminosity function of galaxies in the local universe

I will not talk about the care and feeding of supermassive black holes

Detailed numerical simulations : gravity+ hydrodynamics **does not** produce the universe we see

-many things are wrong e.g. galaxies are too big, too bright too blue, too many, form at wrong time, wrong place

- What else is required?
  - FEEDBACK-The influence of objects on the universe (stars and AGN)
    - many reasons to believe in feedback
  - Stars don't have enough energy
  - **So it has to be AGN**
    - How ?
    - Where ?
    - When ?
- **Need to find the AGN** and measure their effective feedback

How did the universe come to look like it does?

Paradiso Canto 31

Confusion of Theory/Observation

- Theory
  - NO: AGN feedback has very little effect on galaxies, despite the large outflow velocities (Gabor & Bournaud 2014; Roos et al. 2015) or could even enhance star formation (Silk & Nusser 2010; Ishibashi & Fabian 2012; Bourne et al. 2015).
    Yes Springel, DiMatteo & Hernquist 2005 and many others

- Observation
  - Do AGN cause feedback?
    - Yes: ; Maiolino et al. 2012; Olsen et al. 2013; Dubois et al. 2013; Shimizu et al. 2015...
    - No :Coil et al. 2011; Aird et al. 2012,Suh 2017,Villar-Martin et al 2016

Thu, it is not clear what effect AGN have on feedback (negative , positive or none) (Yesuf et al 2017)

General Comments on Observability

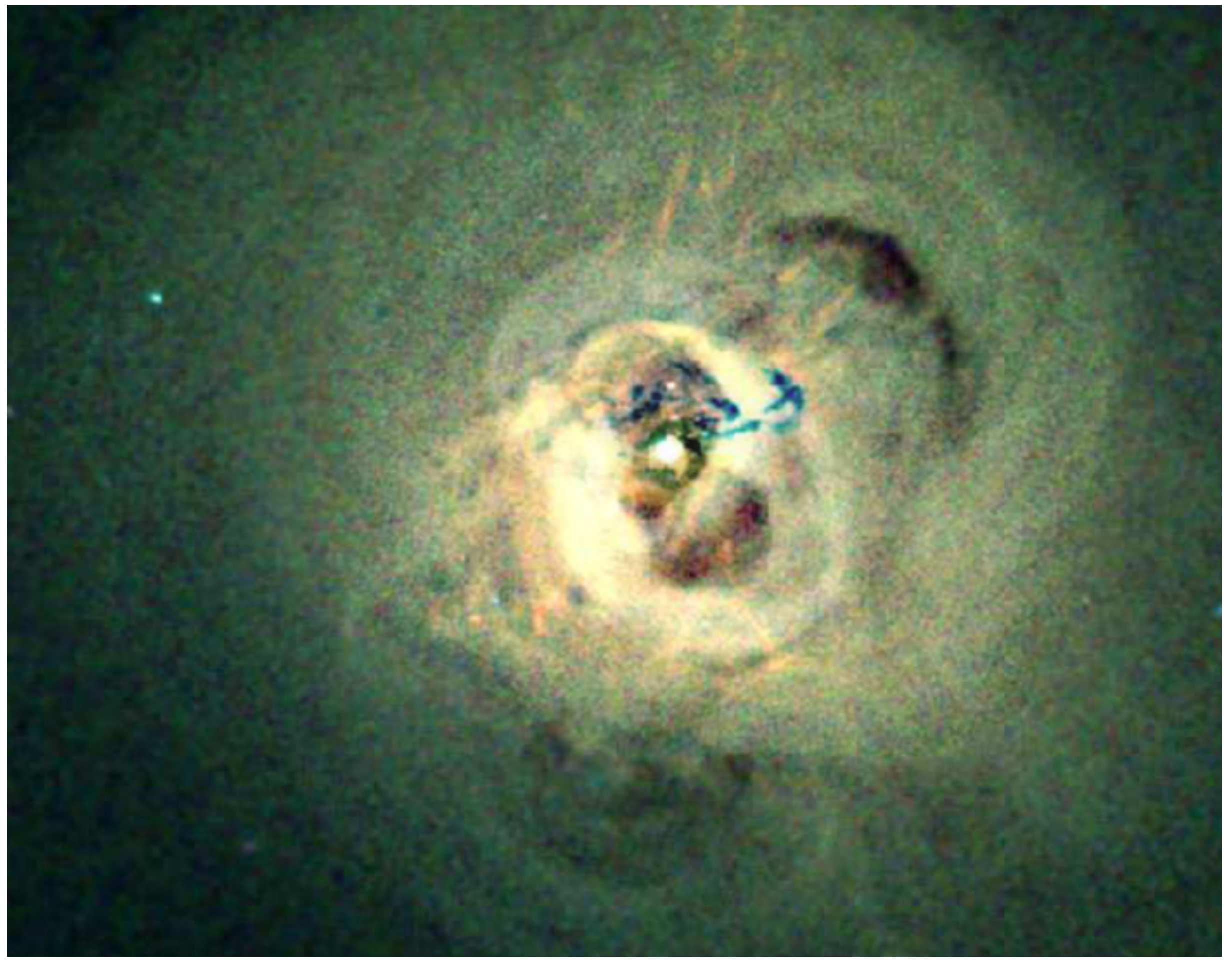
- Feedback can be divided into two general classes, preventive and ejective.
  - Preventive feedback retards star formation by stopping gas from accreting into the ISM
  - Ejective feedback describes processes that remove the gas from the ISM after it has been accreted.
- AGN can do both via
  - heating gas (thermal feedback),
  - driving winds that eject gas (kinetic feedback),
  - ionize or photo-dissociate gas (radiative feedback).
- ***We obviously see winds*** (!) but is that what is causing 'some' AGN feedback and what is observational evidence for either of these effects.

Can Winds Do It?

- If it is winds, then (King and Pounds 2013)
  - the wind needs to have a high column density *N*, high velocity *v*, high covering fraction *f* , all at large distances from BH (*r*) (Fabian 2012)
  - To produce $M_{BH} \sim \sigma^4$ scaling the thrust of the wind needs to be proportional to the Eddington limit.
    - 5–10 per cent of the accretion power, is needed to eject gas from a galaxy.
- Are the WA's (ionized absorbers in x-ray) related to Feedback??

But Can We Observe It?

- Wide variety of observables in clusters of galaxies indicates strong feedback between central radio source (AGN) and x-ray emitting gas (Fabian 2012)
- However these AGN are (at low z) NOT luminous photon emitters
- What about the rest of the universe??



Evidence for Feedback

- The main consequence of feedback for galaxy formation models is on star formation.
- What if anything can we say about star formation in AGN hosts?
- AGN hosts
  - tend to be in massive galaxies (Kauffman et al 2003)
  - almost always spirals at $z<1$ (when morphology is available); at higher z more ETGs (Povic et al 2012)

The Big Questions

- We have had 4 days of AGN winds however we have not discussed why non-AGN folks think they are interesting

Feedback

Is it true that AGN feedback has had a major effect on the formation and evolution of galaxies and have AGN winds been important ??

To quote from King and Pounds

- powerful, highly ionized winds, with velocities~0.1–0.2c are a common feature in X–ray spectra of luminous AGN, offering a plausible physical origin for the well known connections between the hole and properties of its host...The huge SMBH accretion luminosity drives powerful gas flows into the host, making collisions and communication inevitable

Feedback: The basic questions are where, when, how, how much and how do we observationally determine it.

- When does AGN feedback occur: at high z, low z, at all redshifts. Is the amount of feedback a function of cosmic time/galaxy mass/star formation rate.
- In which galaxies is feedback occurring and what are the parameters of the host galaxy that are correlated with feedback. ***Can we measure the direct effect of feedback on star formation.***
- Where in the galaxy are the signatures of feedback found- in the nucleus, in the outer regions, in the halo.
- Are the signatures of feedback different in spirals, ellipticals, rapidly star forming galaxies?
- What is the physical mechanism(s) via which the AGN inhibits, stimulates or modifies star formation?
- ***Are the observed AGN winds related to feedback and if so, how***
- What future observations are necessary to answer these questions?

Where Do AGN 'Live'

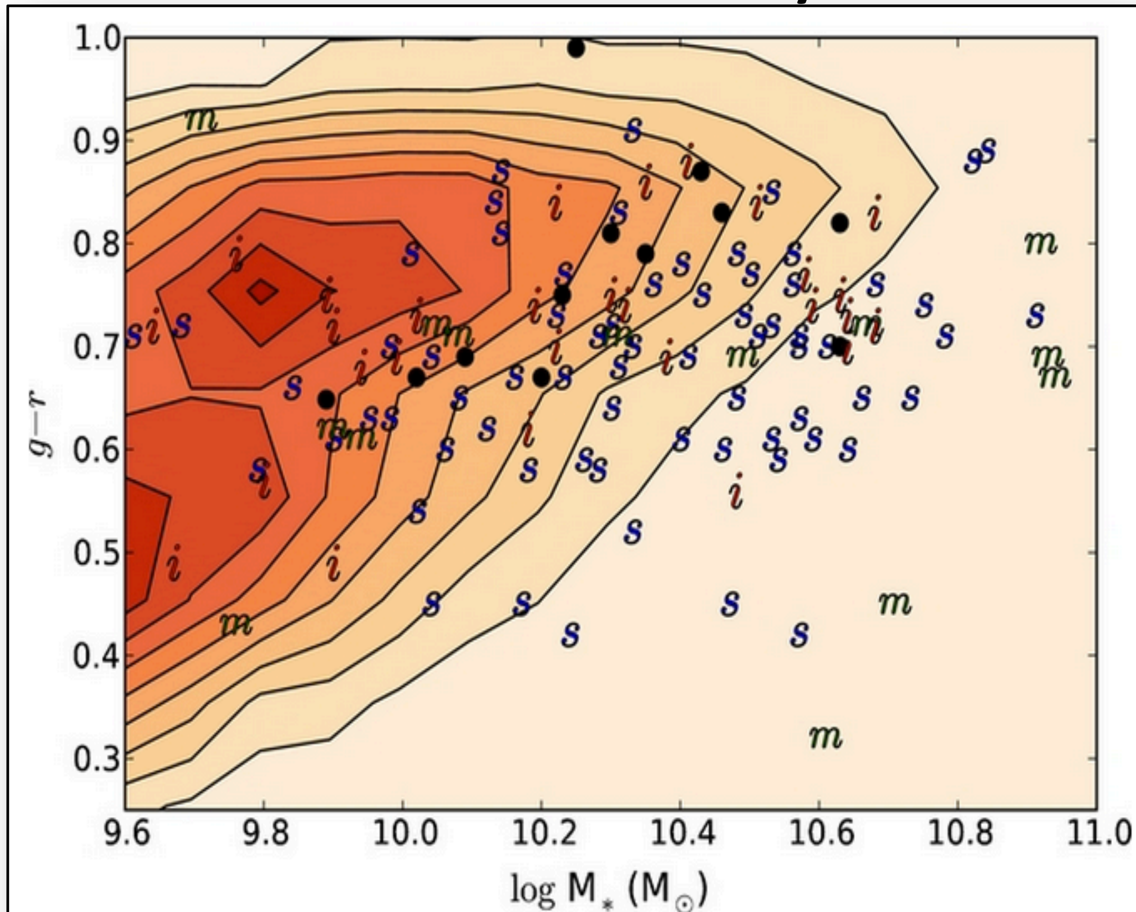
In massive spirals which preferentially lie below the main sequence of star formation

Thus <u>there is a connection between SF and AGN</u>- not clear what the connection is.

Very high rate (~30%) of mergers in BAT AGN

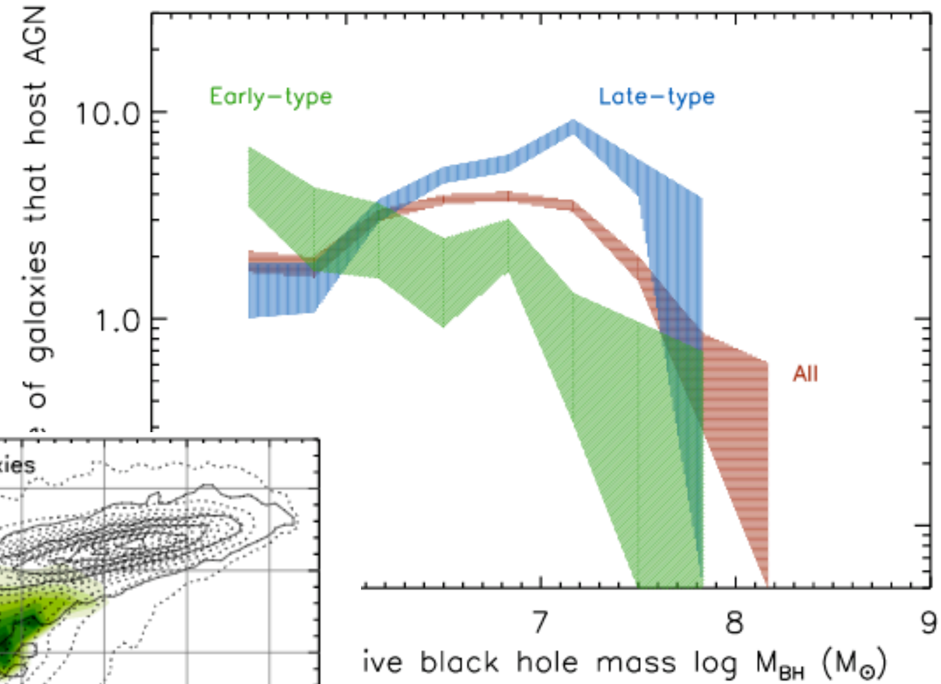
- Long known that optical and x-ray selected AGN lie preferentially in the 'green valley' (Nandra 2007, Schwanski 2010, Koss 2011)
- At low and medium Z AGN are preferentially spirals
  - at high (z>1) galaxy morphologies change

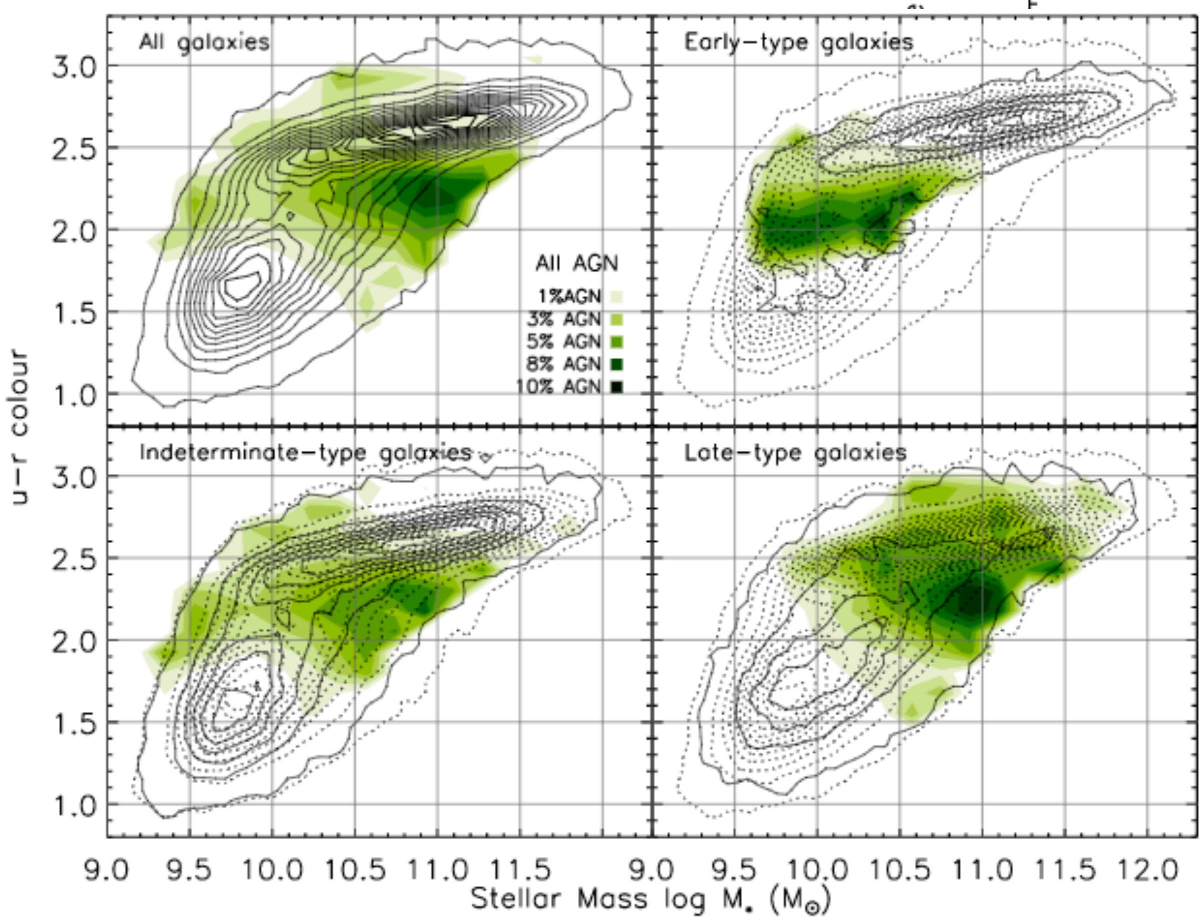
Green Valley



Thus if AGN cause feedback which quenches star formation in massive galaxies it has to occur BEFORE/DURING the mergers which form massive low z ellipticals AND/OR regulate star formation in MW mass galaxies

Optically Selected Type II AGN





Schawinski+10a

Optically selected Type Iis do not lie in the same regions of color-mag, morphology as field galaxies.
Late type galaxies are more likely to host AGN iu this sample

a Schawinski

PG Quasars and Main Sequence of SF

PG Quasars often have suppressed SF

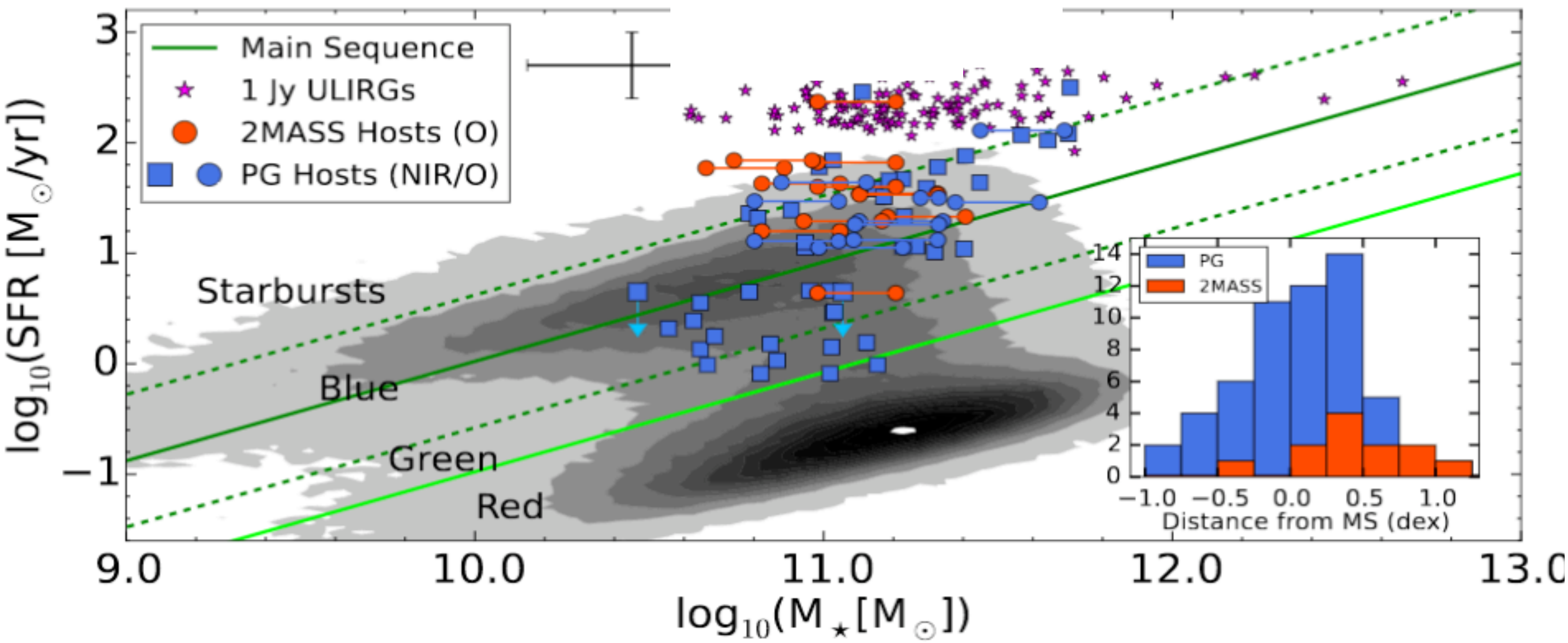
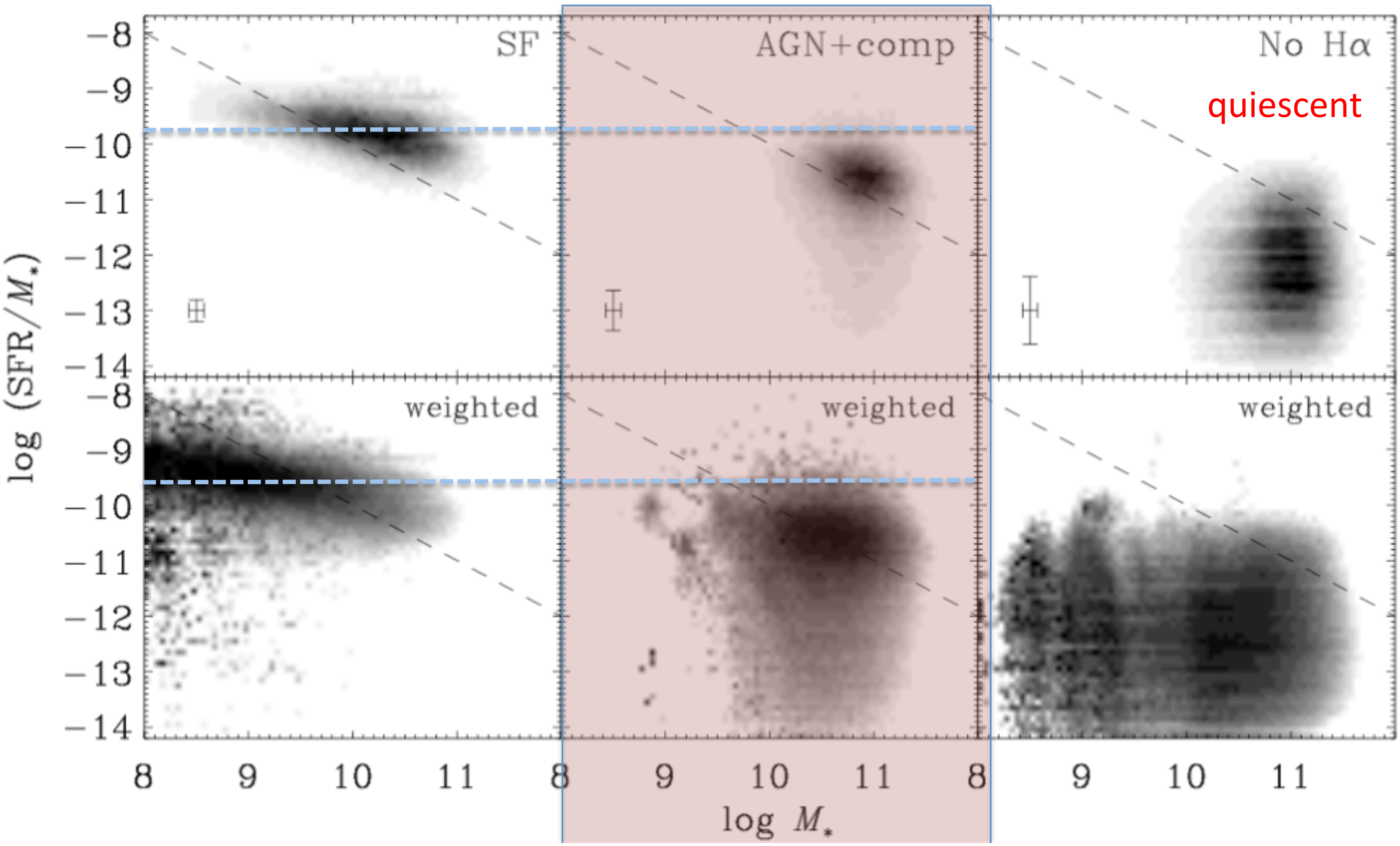


FIG. 2.— SFR–$M_\star$ relation for 67 2MASS (*red*) and PG (*blue*) quasar hosts. Galaxies with NIR measurements appear as squares, v
hose with optical photometry are shown as two circles corresponding to two K-corrections (see text). The typical error-bar is also n
Over-plotted data include 118 complete 1 Jy ULIRGs (*pink stars*) and 587,673 SDSS DR7 galaxies (*filled grey contours*). Contours in
cale show the number density of the SDSS sample, and demonstrate a bimodal distribution. The *dark green solid line* describes the
equence (Peng et al. 2010) with two dashed lines 0.6 dex above and below the sequence; the *lime solid line* is visually determined a
oundary between green valley and red galaxies, that is about 10 times below the sequence. In addition, two light blue *downward ar*
re for PG 0026+129 and PG1121+422, whose SFRs are 3σ values. The subplot at the right lower corner shows the distributions o
istance of our 2MASS (red) and PG (blue) objects to the main sequence.

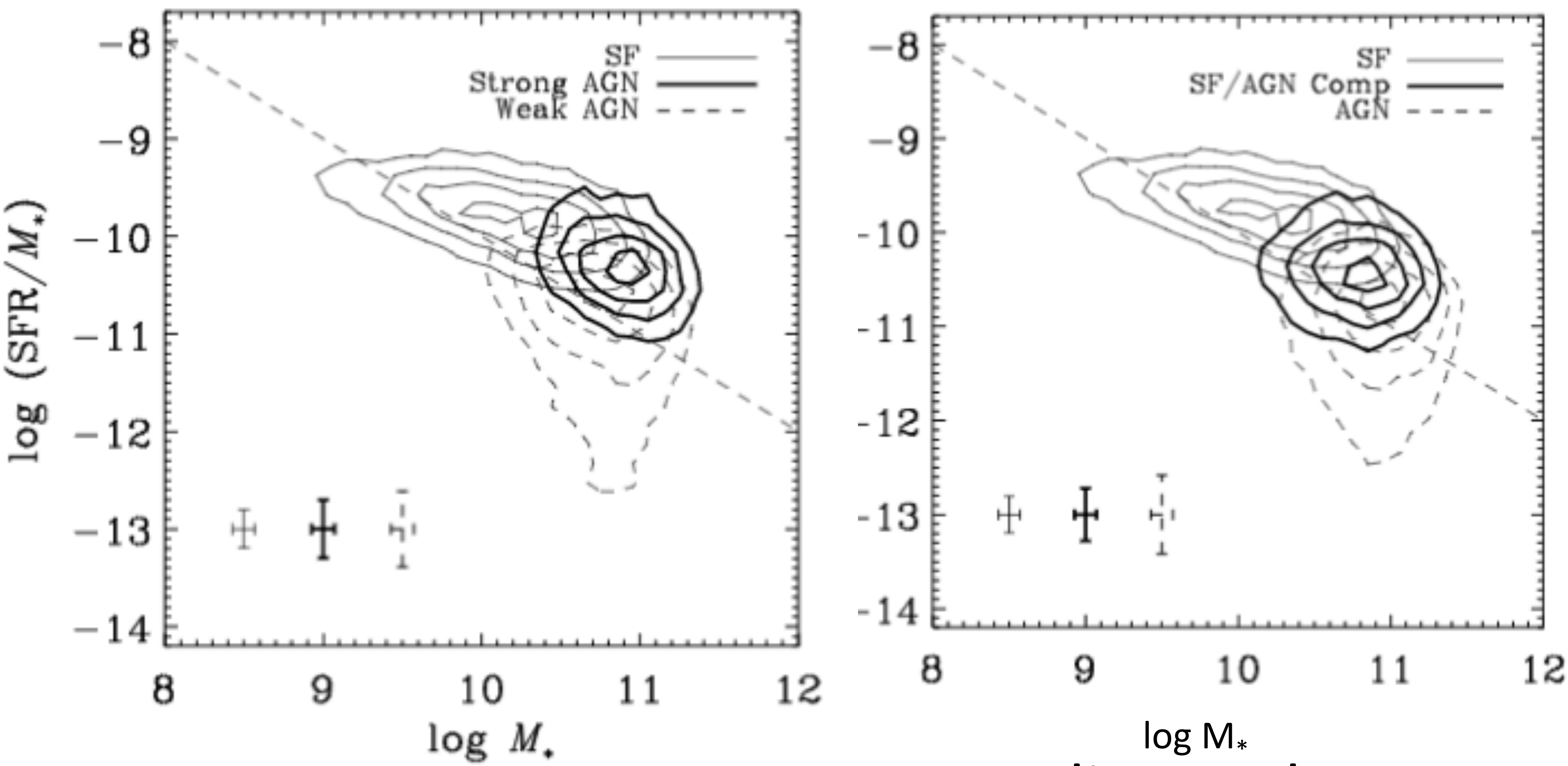
Discovery of Relation (Salim et al 2007)

- "We find that the three have distinct star formation histories, with AGN lying intermediate between the star-forming and the quiescent galaxies."



Discovery that AGN have Different SFR as a Population

<u>'Weak AGN lie more off the MS'</u>



Salim et al 2007

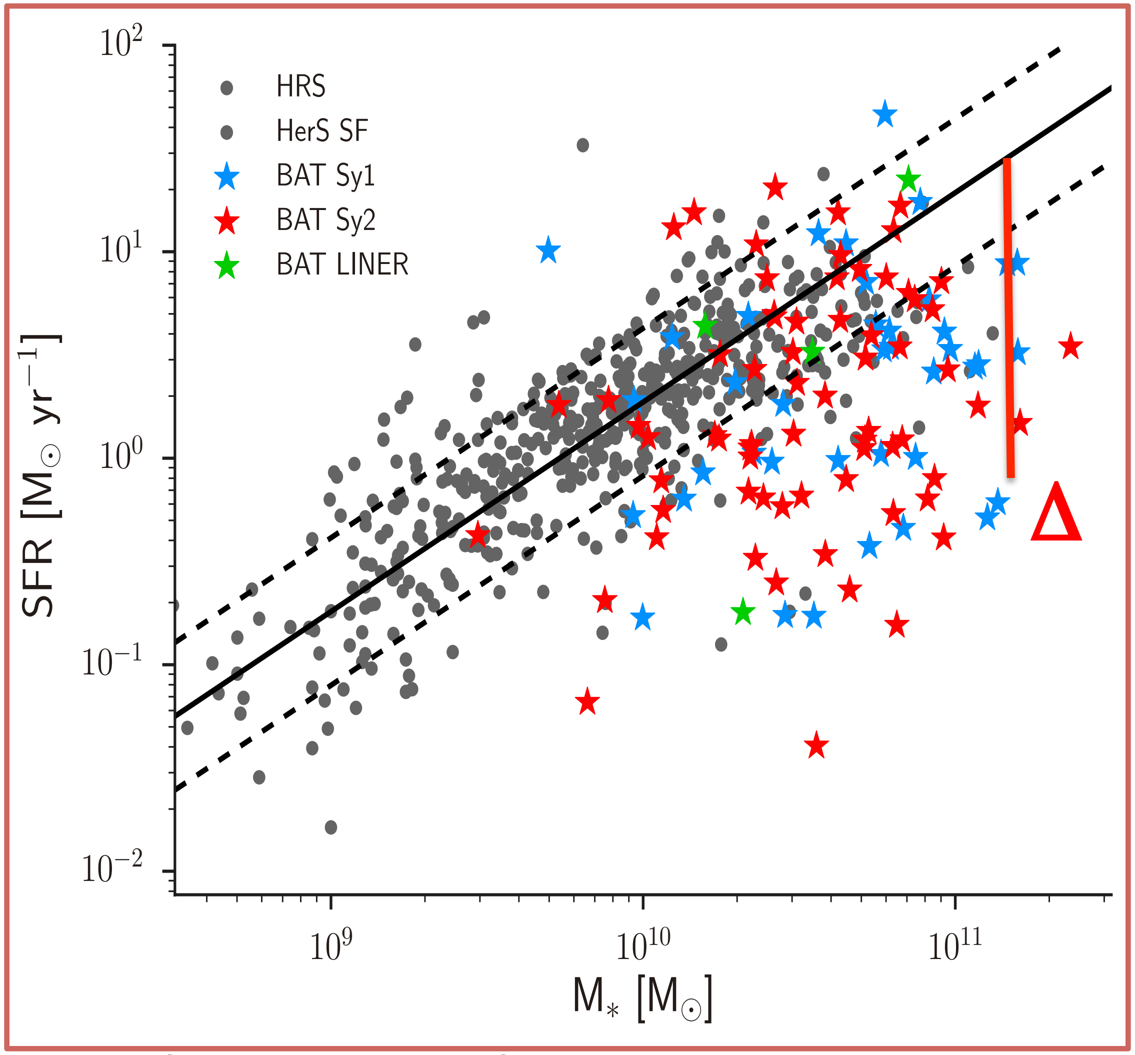
Many Confirmations of This

- Shimizu et al 2015 (x-ray), Leslie et al 2016 (optical) , Mullaney et al (various) , Matsuoka et al 2015, Ellison et al. 2016b (IR AGN) ...

  - BUT Coil et al claim that this is a selection effect: Trump et al have shown that detection of weak AGN is reduced in the presence of strong star formation.
  - HOWEVER this is not true for x-ray selection

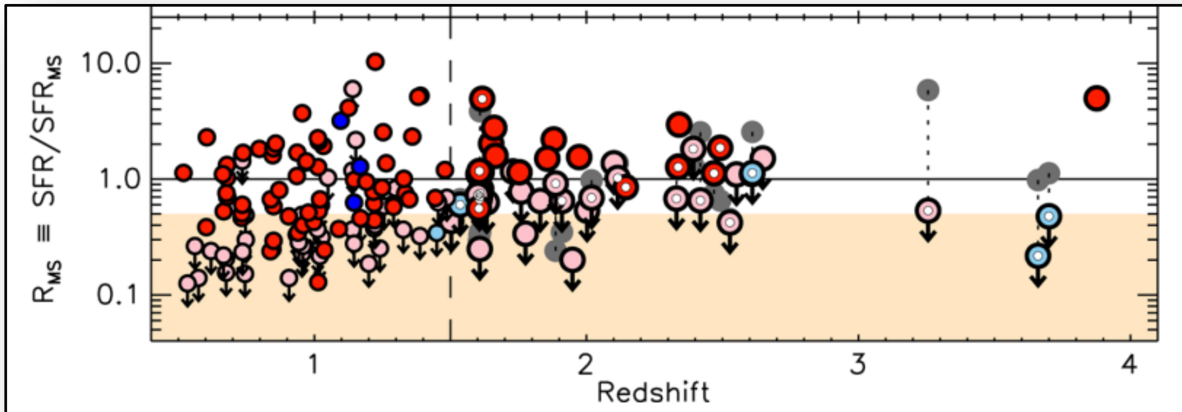
BAT AGN and the Main Sequence

- BAT AGN and HRS SFR and stellar mass determined with same methods
- 5% AGN Above MS
- 28% AGN Inside MS
- **66% AGN Hosts Below MS**
- Split Below region into 3
  - > 1σ (28%)
  - > 2σ (18%)
  - > 3σ (20%)
- **Large fraction of AGN with decreased sSFR = SFR/M$_*$**

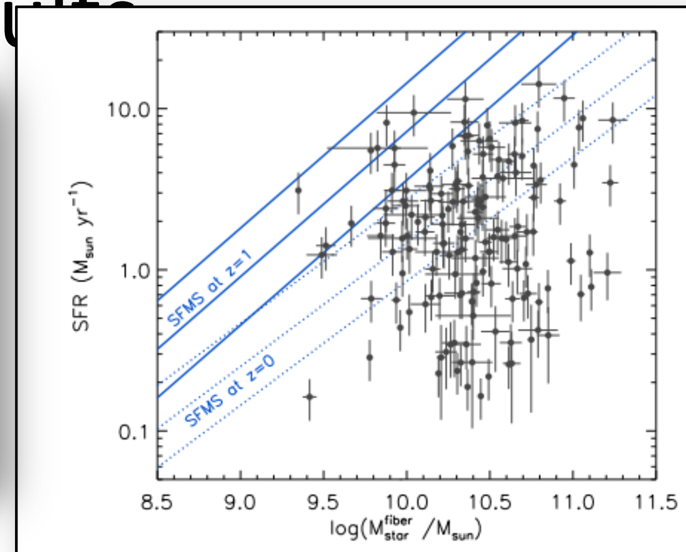


Shimizu et al 2015

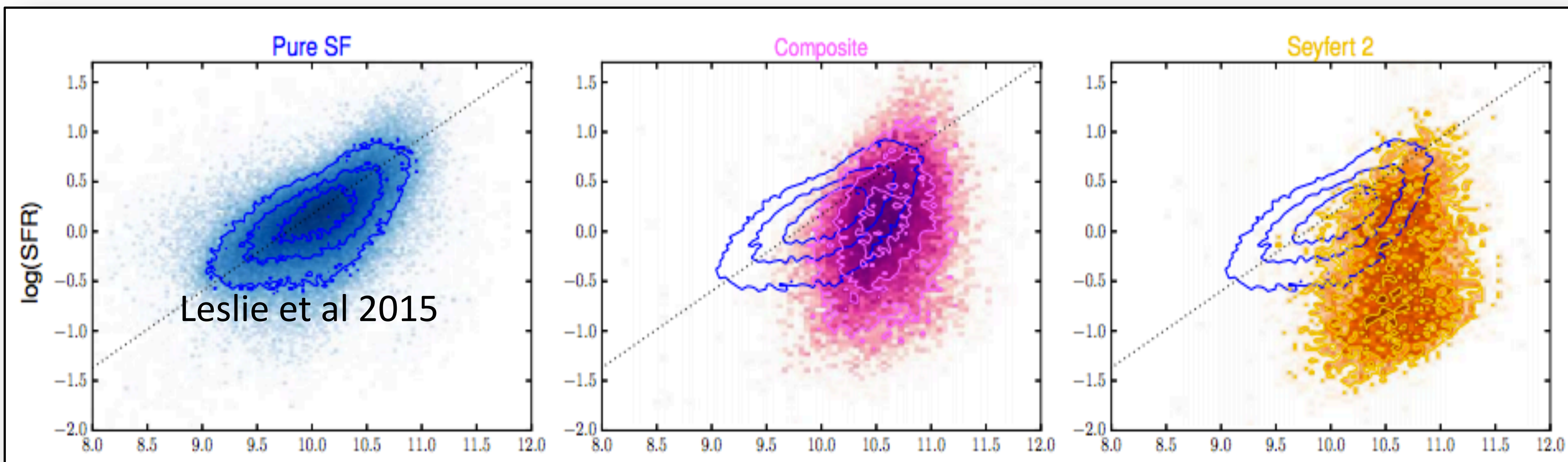
AGN Lie Below the Main Sequence- similar other recent results



Mullaney et al 2015

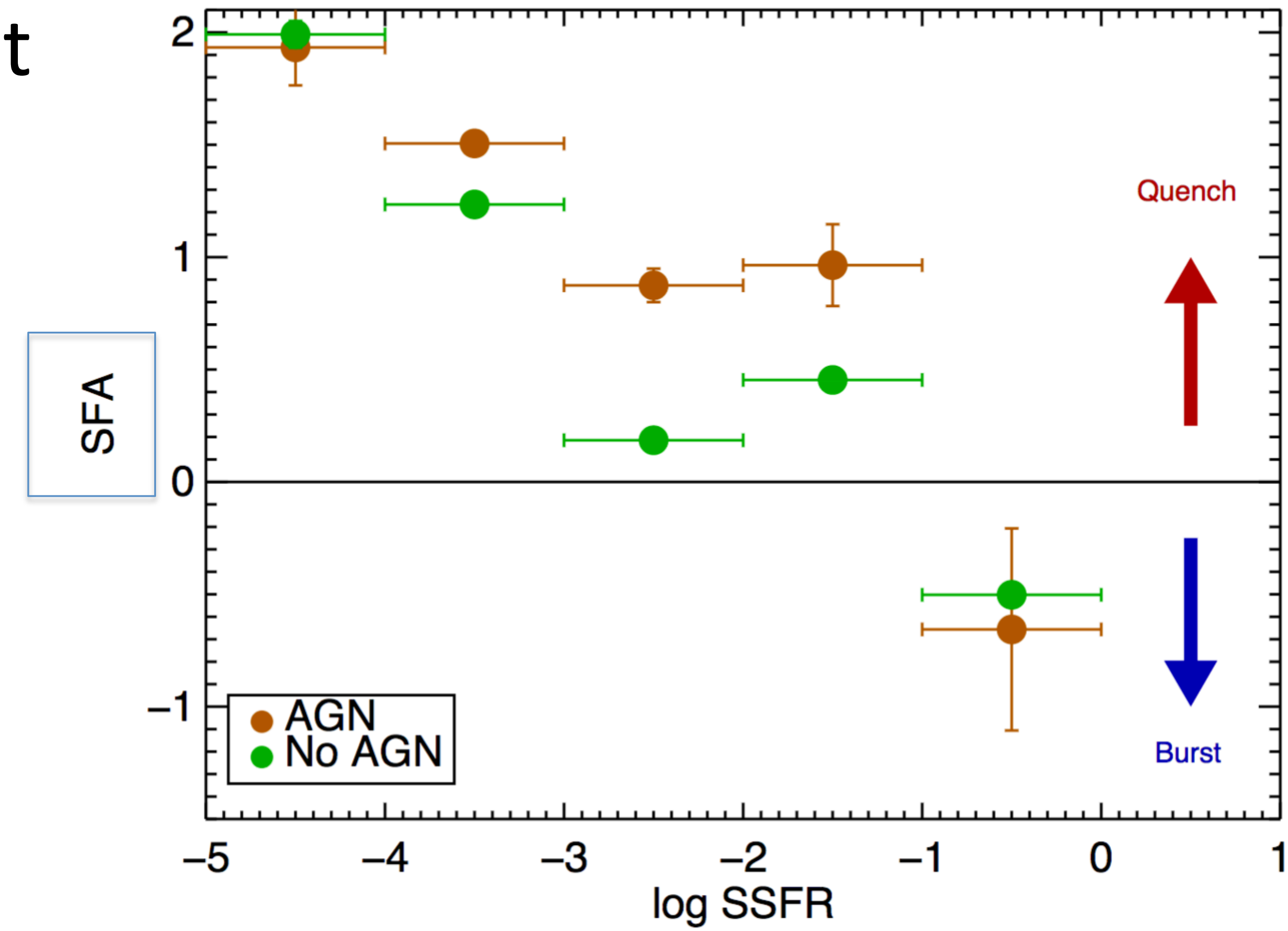


Matsuoka et al 2015



Leslie et al 2015

Martin et al 2017

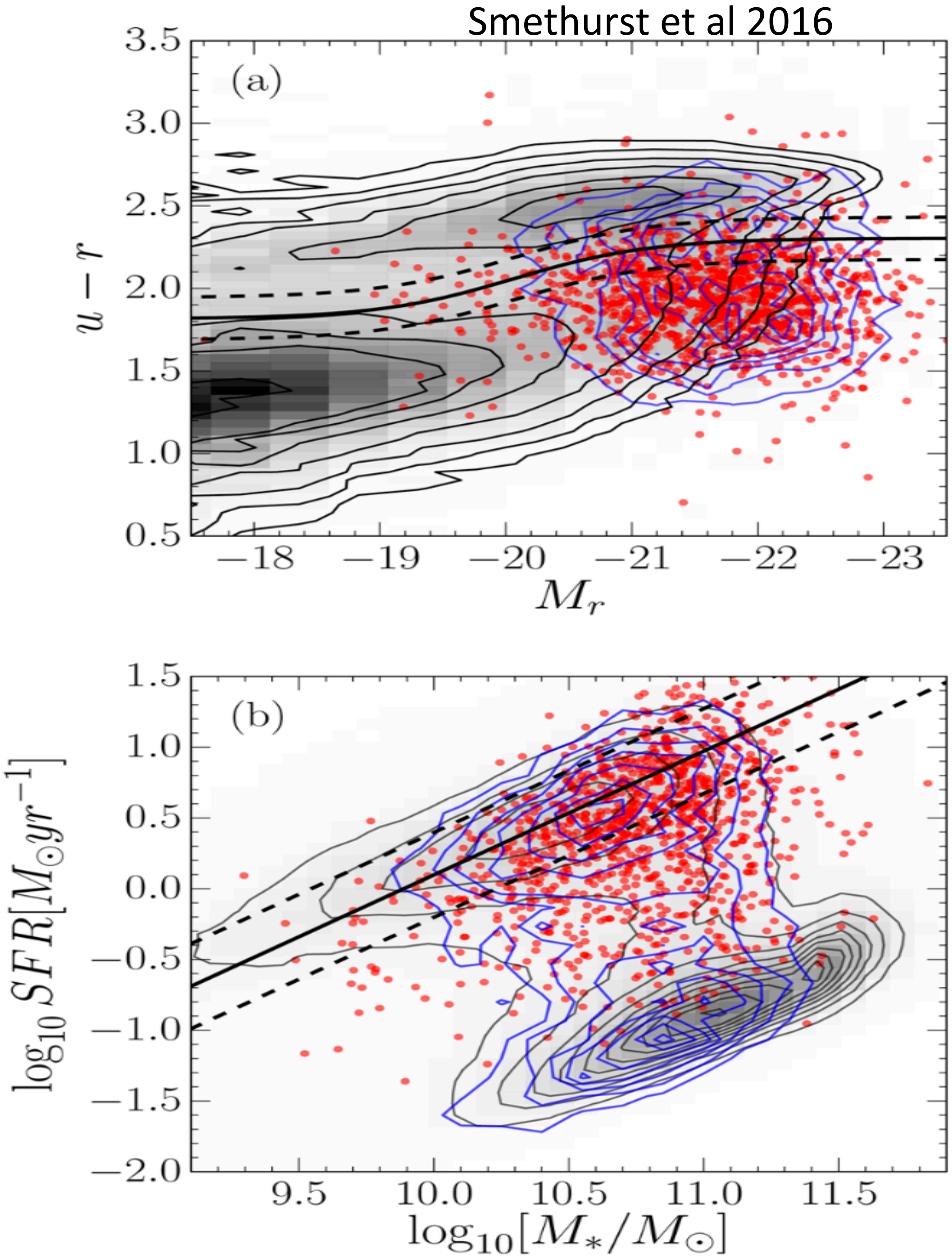


SFA=instantaneous time derivative of
the star formation rate -Star Formation Acceleration

even more

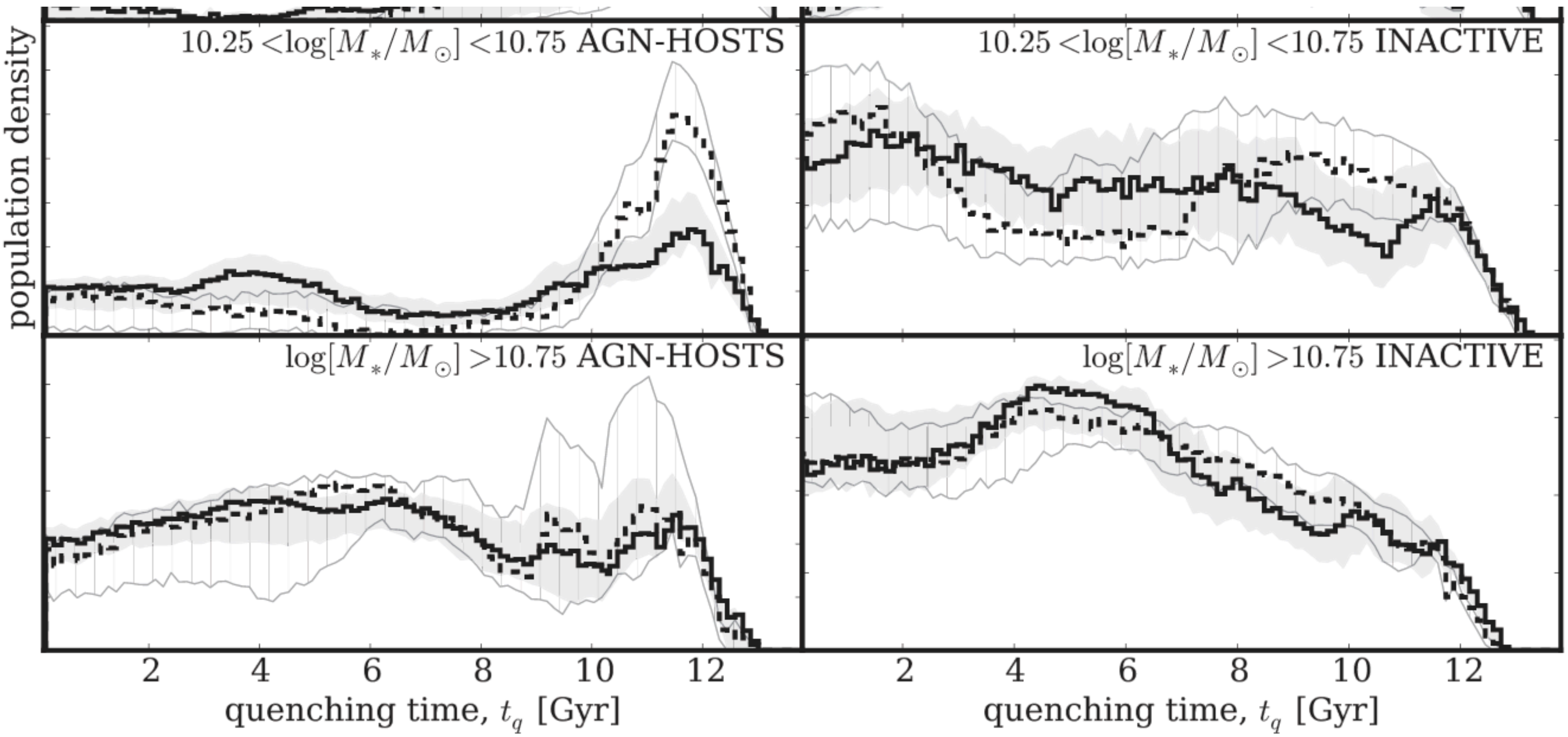
red dots AGN

grey contours 'normal' galaxies



AGN Hosts Quench More Recently-

Smethurst et al 2016 (Seyfert IIs)



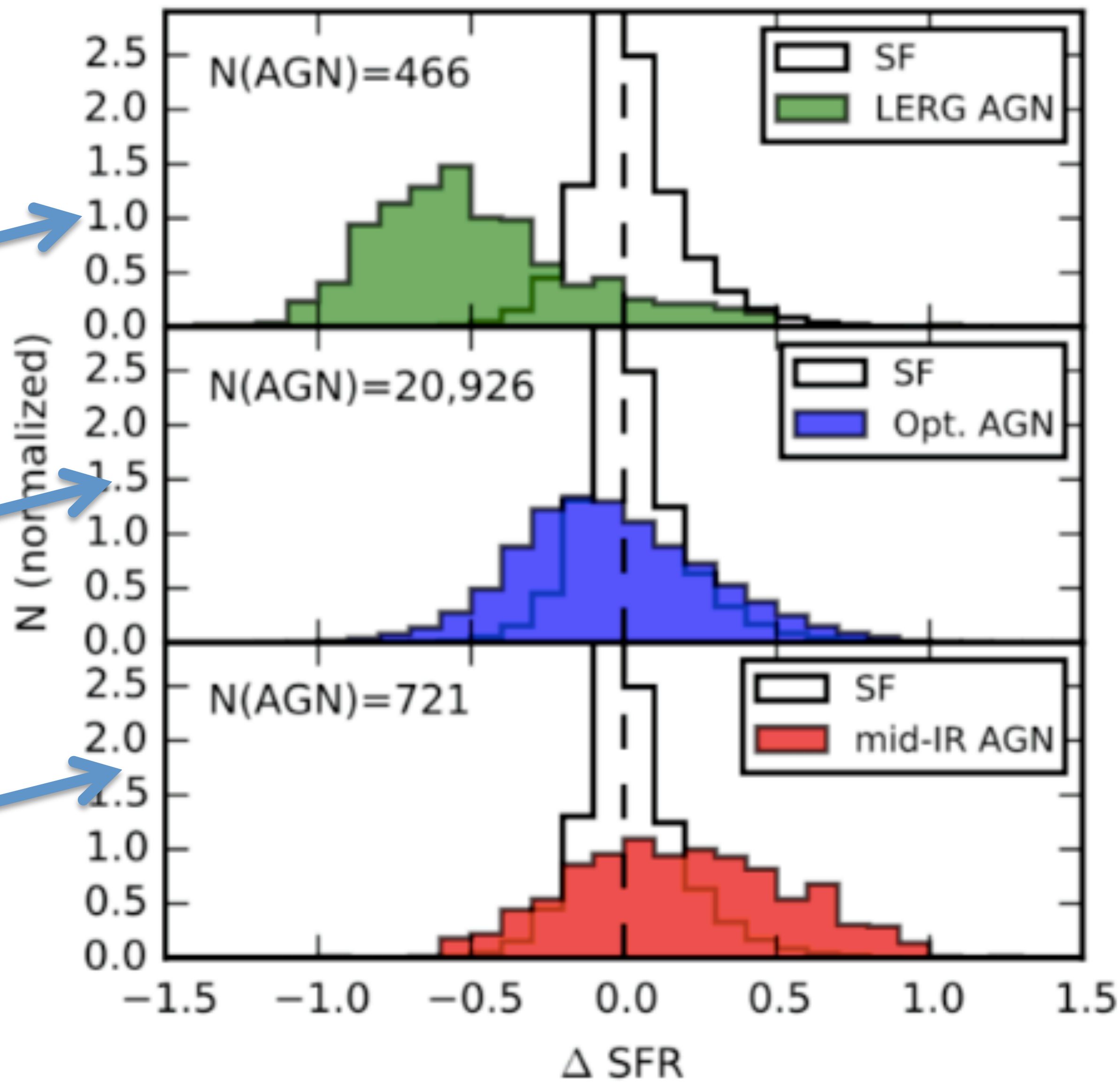
Both recent, rapid quenching and early, slow quenching are observed in the population density within the AGN-HOST population
The dominant mechanism for quenched and quenching galaxies currently hosting an AGN is for rapid quenching which has occurred very recently. This result demonstrates the importance of AGN feedback within the host galaxy population,

Star Formation and AGN Type

Radio selected AGN tend to lie in red/ dead galaxies (ellipticals)

Optical selected AGN tend to have objects below MS

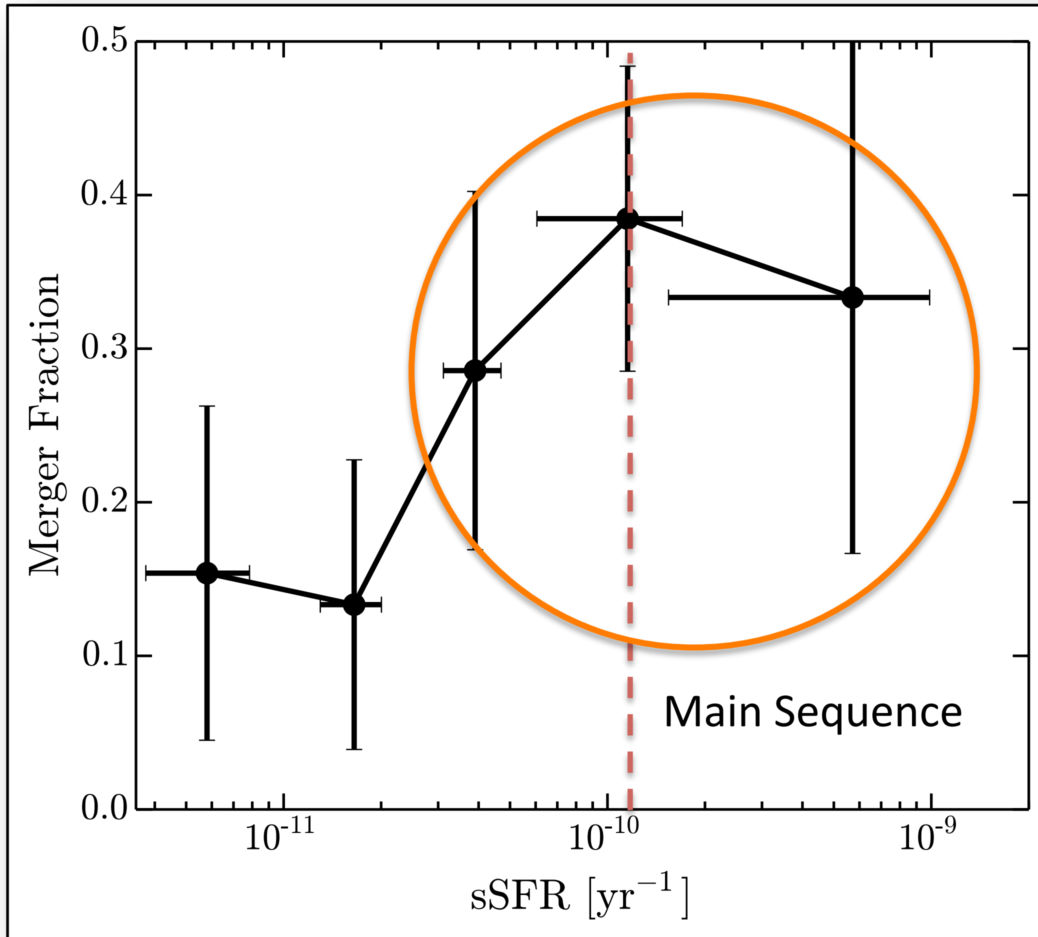
IR selected AGN tend to have 'high' SFR



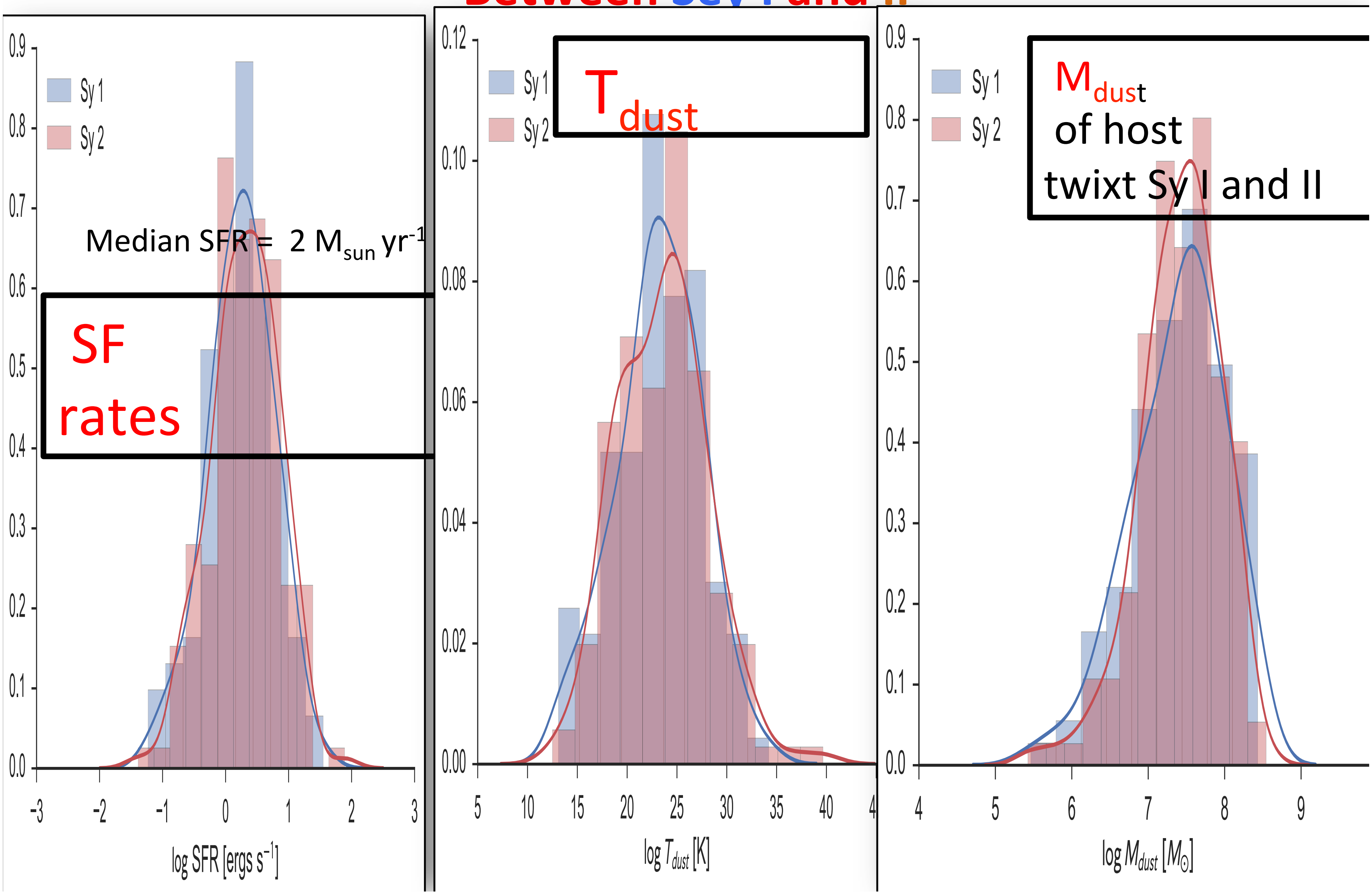
Ellison+16

Increase in Merger Fraction with sSFR

- Very high rate (~40%) of mergers in BAT AGN **<u>above and in the MS</u>-** compared to 2% of normal 'field' galaxies
- **Almost all AGN below MS NOT in mergers**
    - Merger boosting SFR?
    - AGN quenching SFR?
- Merger-AGN with companion
    - < 30 kpc away
    - < 500 km/s radial velocity



Star-Forming Properties of BAT AGN Hosts- **No Differences Between Sey I and II**



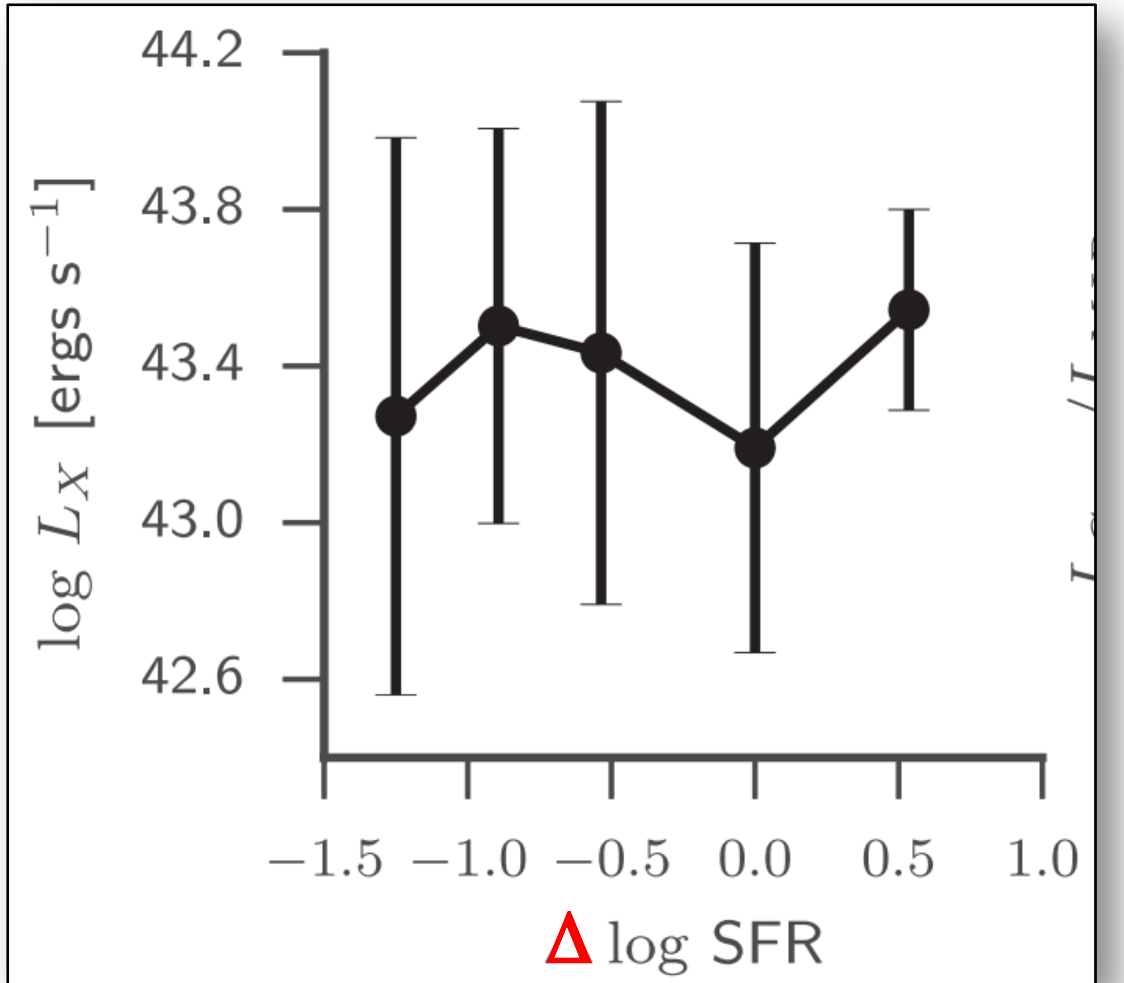
sSFR **Not** Correlated with L_X

- No correlation between distance from the MS

Δ SFR and the strength of the AGN

  - 14-195 keV emission essentially instantaneous AGN strength
  - SFR averaged over ~10 Myr
  - 'Flicker' model for AGN: short timescale variability produces scatter in SFR-AGN correlation?

Hickox et al 2014 and Schawinski et al 2015



Shimizu et al 2015

No Correlation with L(x)

Original Salim et al results found that 'star formation suppression' was more common in 'weak' AGN

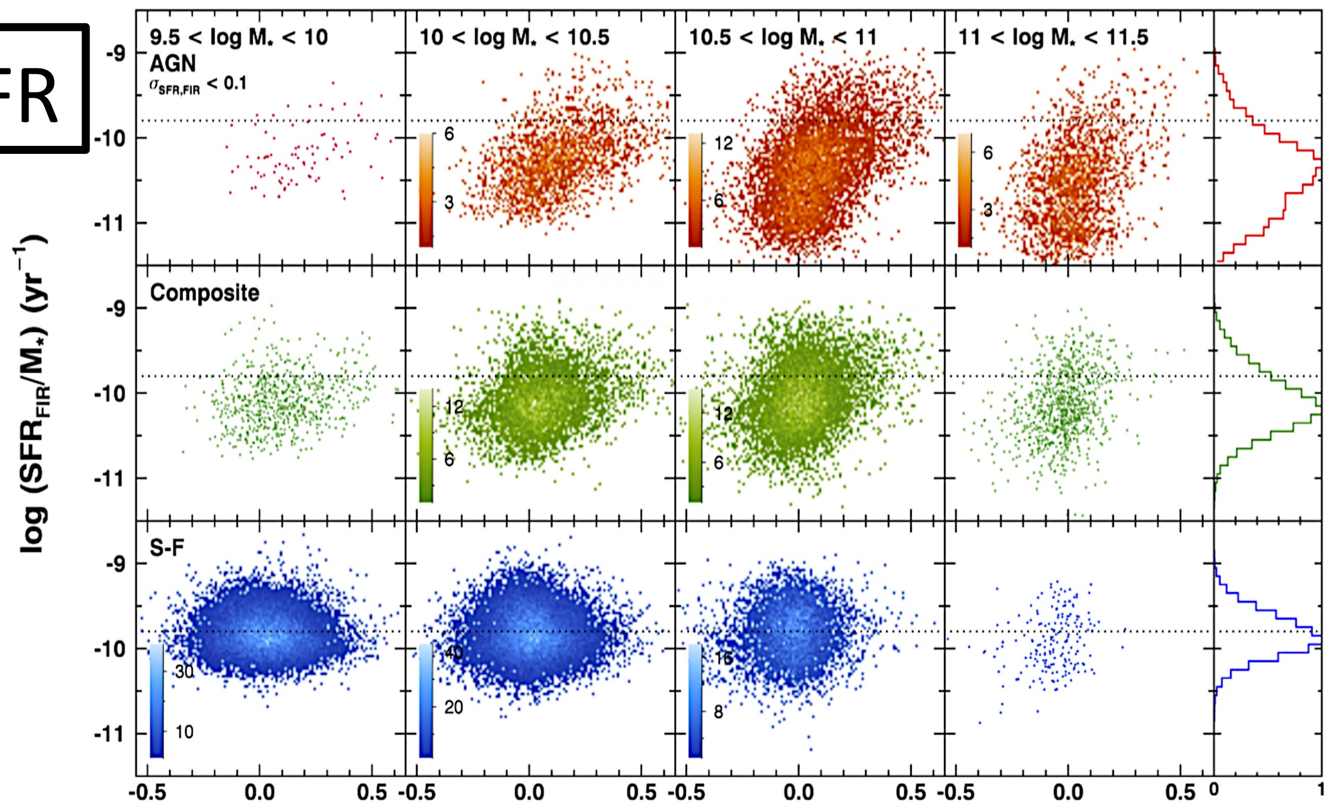
Woo et al 2017 find that 'star formation suppression' is stronger in AGN with weak winds

Leung et al 2017 find no correlation of 'star formation suppression' between AGN with and without outflow

What is going on ?? Are winds relevant at all !

Winds and sSFR

- Woo et al 2017
  non-AGN galaxies form a star forming sequence with a constant SSFR



Outflow speed

AGNs have lower SSFR than SF galaxies- at fixed stellar mass.

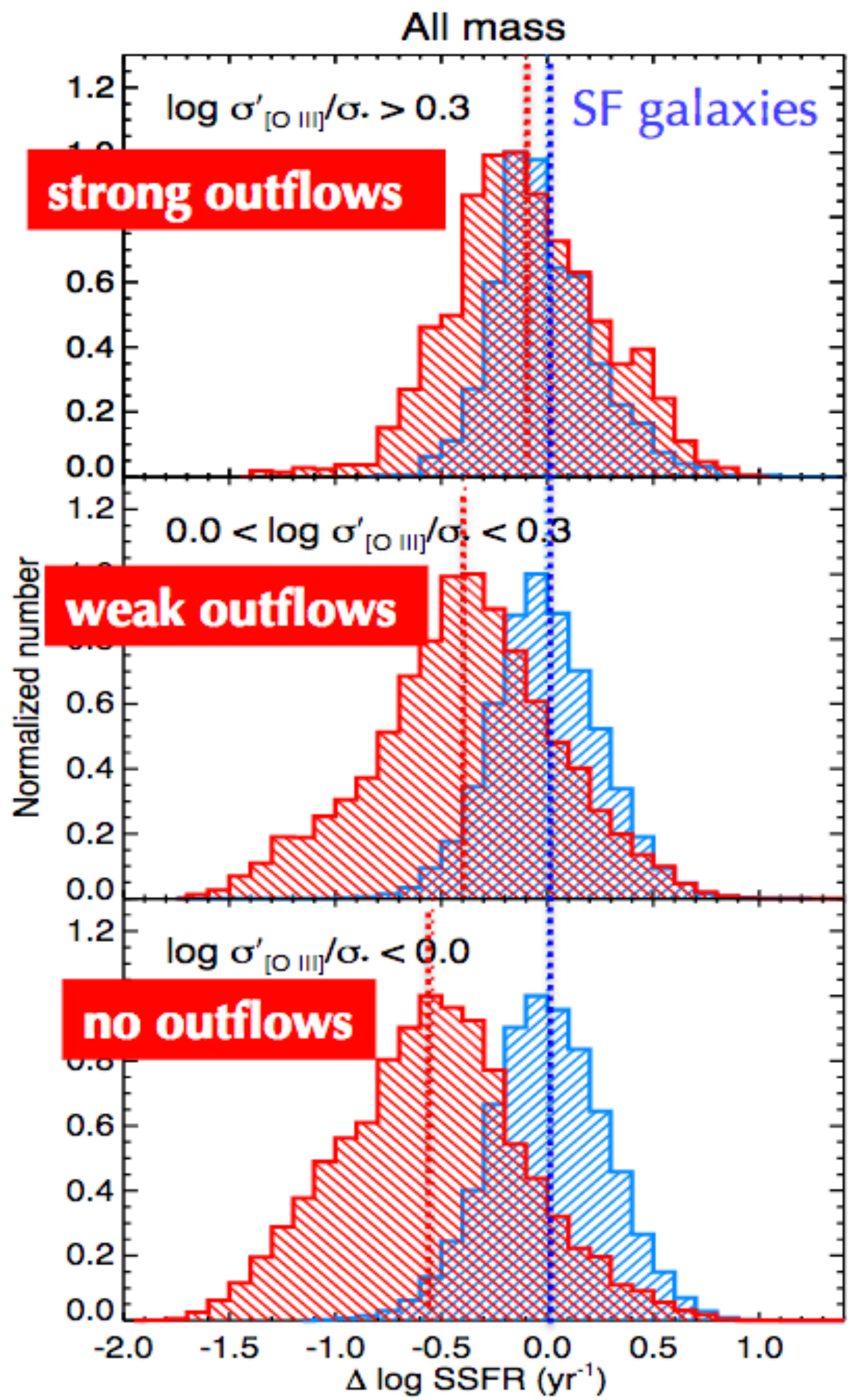
SSFR of AGN sample increases with increasing outflow velocities-
FASTER OUTFLOW- MORE STAR FORMATION

AGNs with no outflow have lower SSFR.

- AGNs with strong outflows have similar SSFR compared to SF galaxies. No suppression, no enhancement.
- AGNs with no outflows show much lower SSFR.

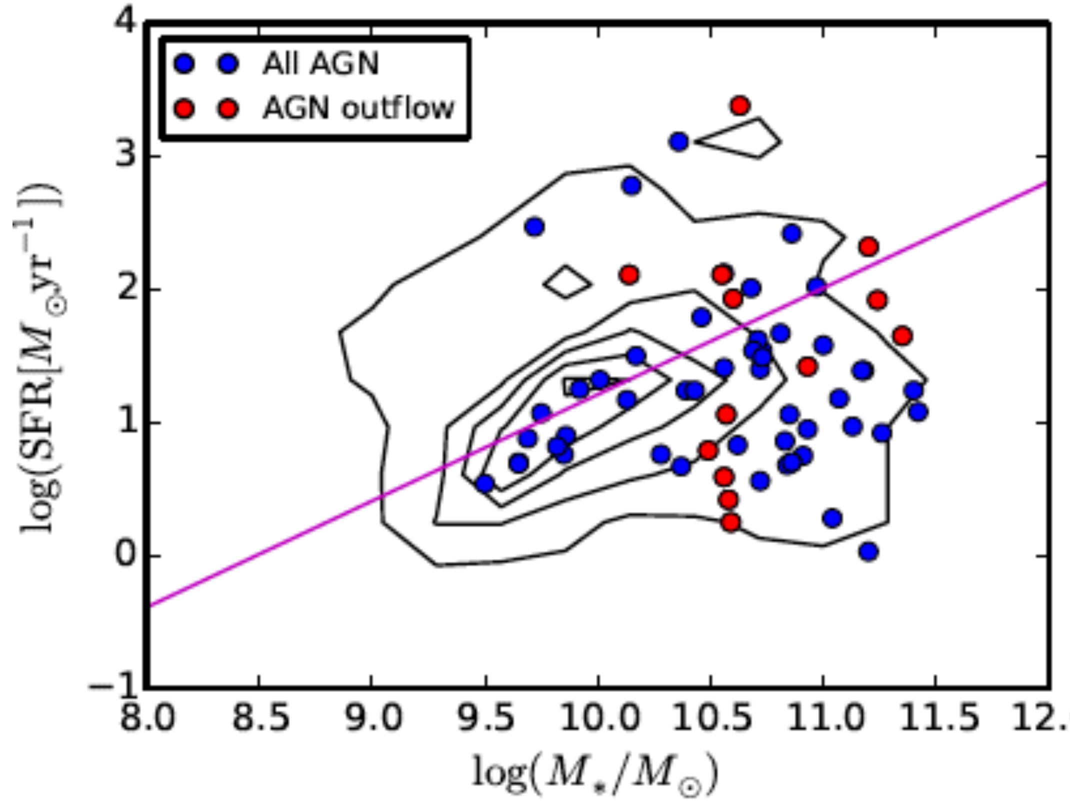
Consistent with idea that blowout occurred 'before'

Woo et al 2017

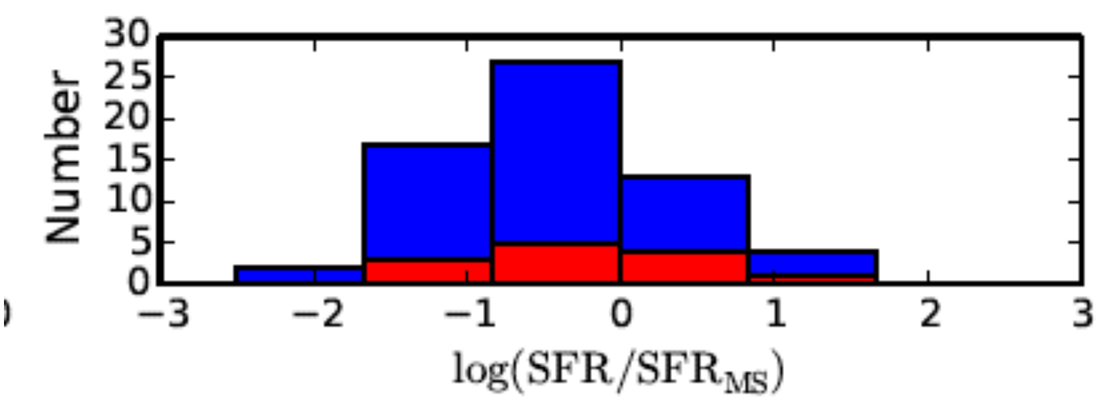


Another Story??-Outflows and SF in AGN Hosts

Leung et al state that their results imply that the presence of AGN-driven out flows does not quench star formation.



log($M_*/M_\odot$)



Leung et al 2017

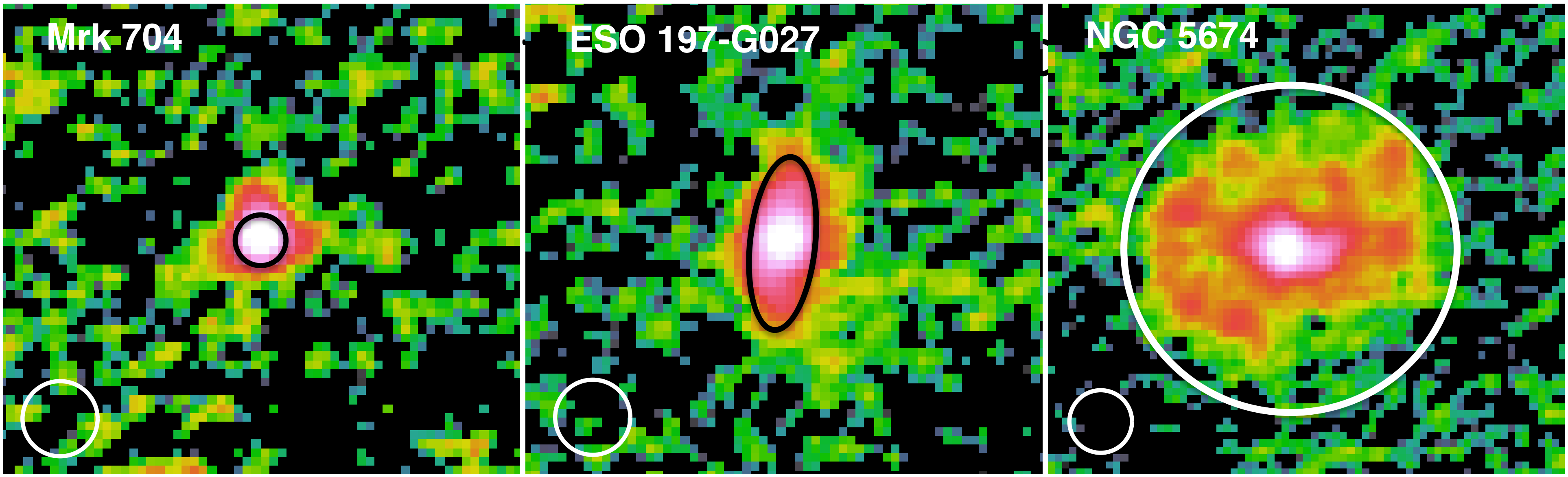
Anti-correlation of outflows and quenching?? Woo et al 2017

- AGNs with strong outflow signatures -similar specific star formation rate (SSFR) to that of star forming galaxies.
- AGNs with weak or no outflows have an order of magnitude lower SSFR
- AGNs with current strong outflows do now show any negative AGN feedback -take the order of a dynamical time to impact on star formation over galactic scales (e.g. wind stops before we observe reduction in SF)
  - low Eddington AGNs have lower SSFR than SF galaxies, while high Eddington AGNs have comparable SSFR with respect to SF galaxies.

A strong clue to where feedback occurs

- In the BAT selected AGN SF is mostly nuclear yet many are below the MS- e.g. overall SF suppressed, BUT nuclear SF enhanced (also seen in IR samples with AO, Garcia- 2016)
- It seems as if AGN is suppressing gas inflow, but not SF itself...
  - 2 layer process: strong SF in nucleus, prevent large scale inflow

AGN Host Galaxies Are Compact in Mid-IR



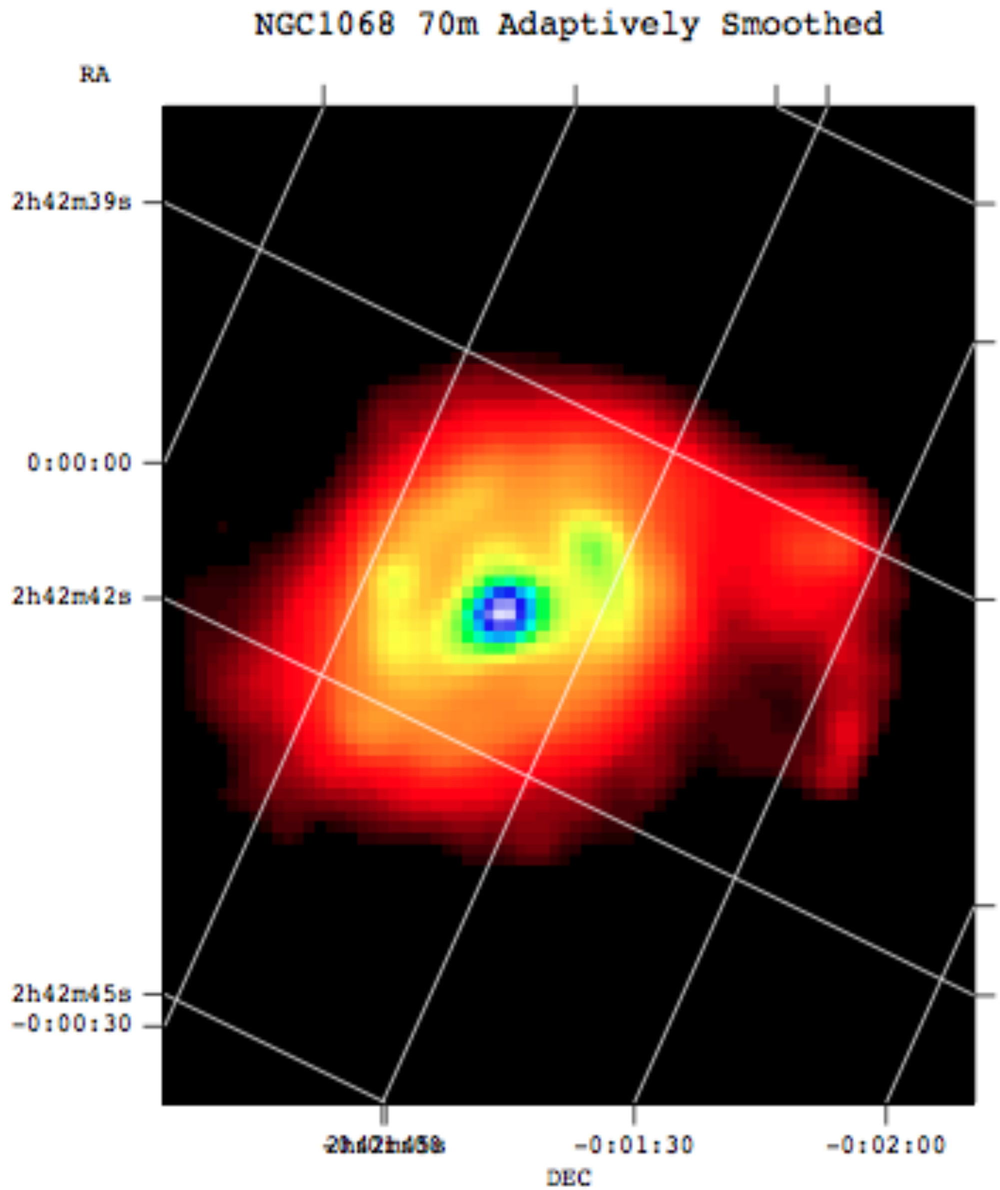
Mushotzky et al 2014

- 37% are <u>unresolved</u> sizes < 2 kpc
- 35% <u>partially extended</u> sizes ~ 5 kpc
- 28% fully resolved sizes ~ 10 kpc

<u>*SFR surface density exceeds threshold for starburst driven winds in*</u> 30%-50% of our sample [SFR > 0.1 $M_{\odot}$/yr kpc^2 (Heckman, 2001)]

Closest AGN NGC1068, NGC4151 Herschel 70μ Image

- NGC1068~50% of the 70 and 160μ flux and 20% of the 250μ is point-like
- In NGC4151 80% of 70μ flux is point-like (<100pc in size)



New Evidence that AGN Effect Their Hosts

- Ricci et al (2017, Nature submitted) the 'primary' difference between type I and II AGN is their Eddington ratio
  - the transition between type I and II occurs at the Eddington ratio for dust (Vasudevan and Fabian 2009)

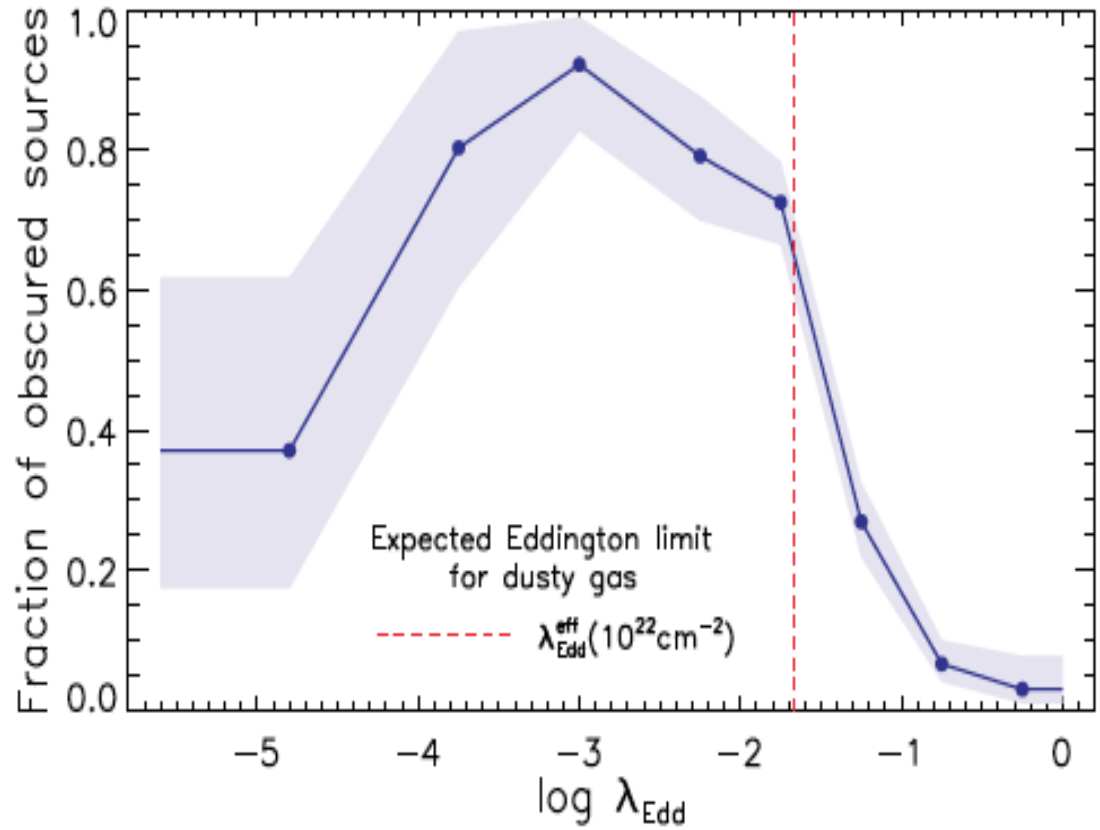


Figure 1: **Relation between the fraction of obscured AGN and the Eddington ratio.** The fraction of obscured Compton-thin [$10^{22} \leq$

Is this connected to 'AGN' feedback- ?? But Type IIs are not 'more' quenched than type Is (Shimizu et al 2017)

Conclusion

- Many pieces of evidence that at low z host galaxies of AGN tend to have have suppressed star formation
- But galaxies with highest outflow speed have highest specific star formation rate
- Star formation is enhanced on small scales- must be suppressed on large scales.
- Be careful in using hosts of type II AGN as model for for type Is