AGN triggering in star-forming galaxies:

A tight connection at early times and its break-down at late times

Stéphanie Juneau

CEA Saclay

Collaborators: Elisabete da Cunha (MPIA), Orianne Roos (CEA), Frédéric Bournaud (CEA), Jared Gabor (CEA), Stéphane Charlot (IAP), James Mullaney (Sheffield), Mark Dickinson (NOAO), Matt Lehnert (IAP), Emanuele Daddi (CEA), David Elbaz (CEA), Jon Trump (PSU) and others (GOODS & AEGIS teams)

SFR-AGN have a relationship best described as "It's complicated"

– D. Farrah

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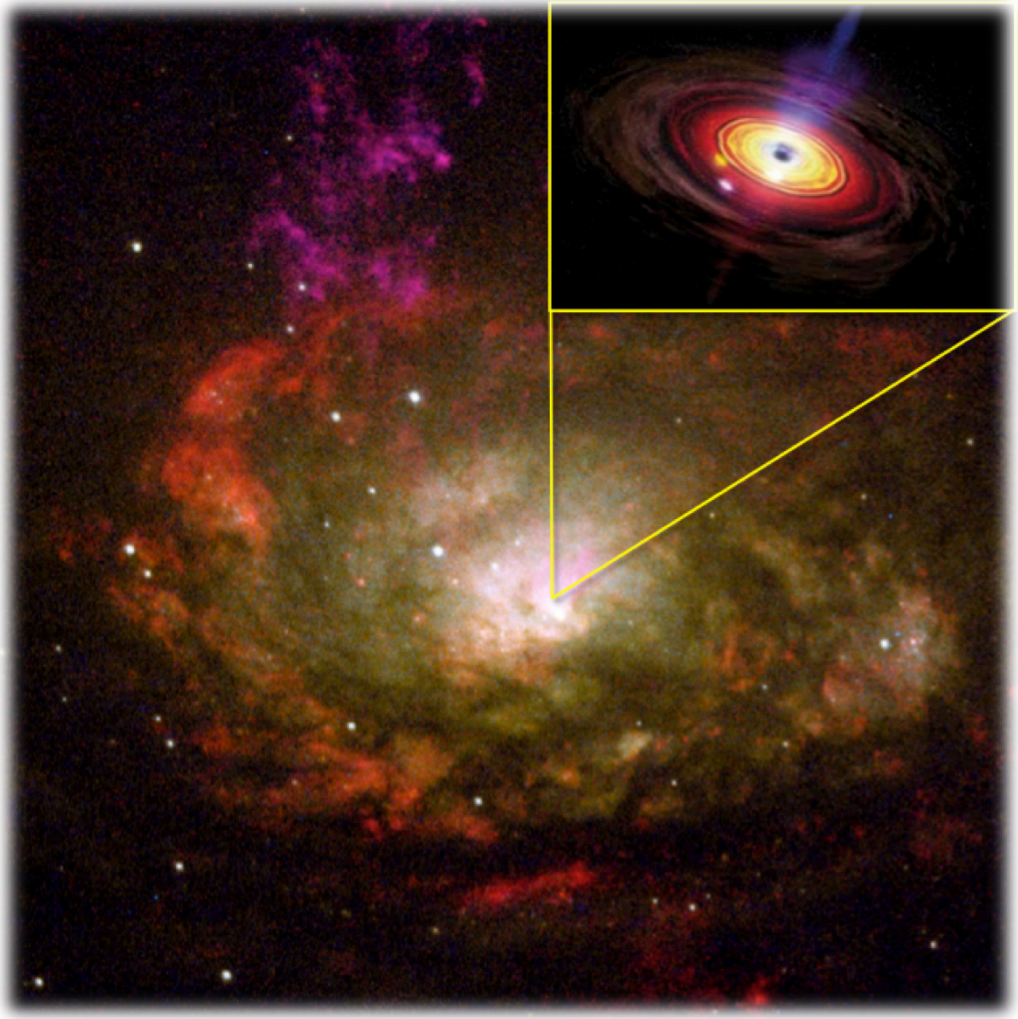
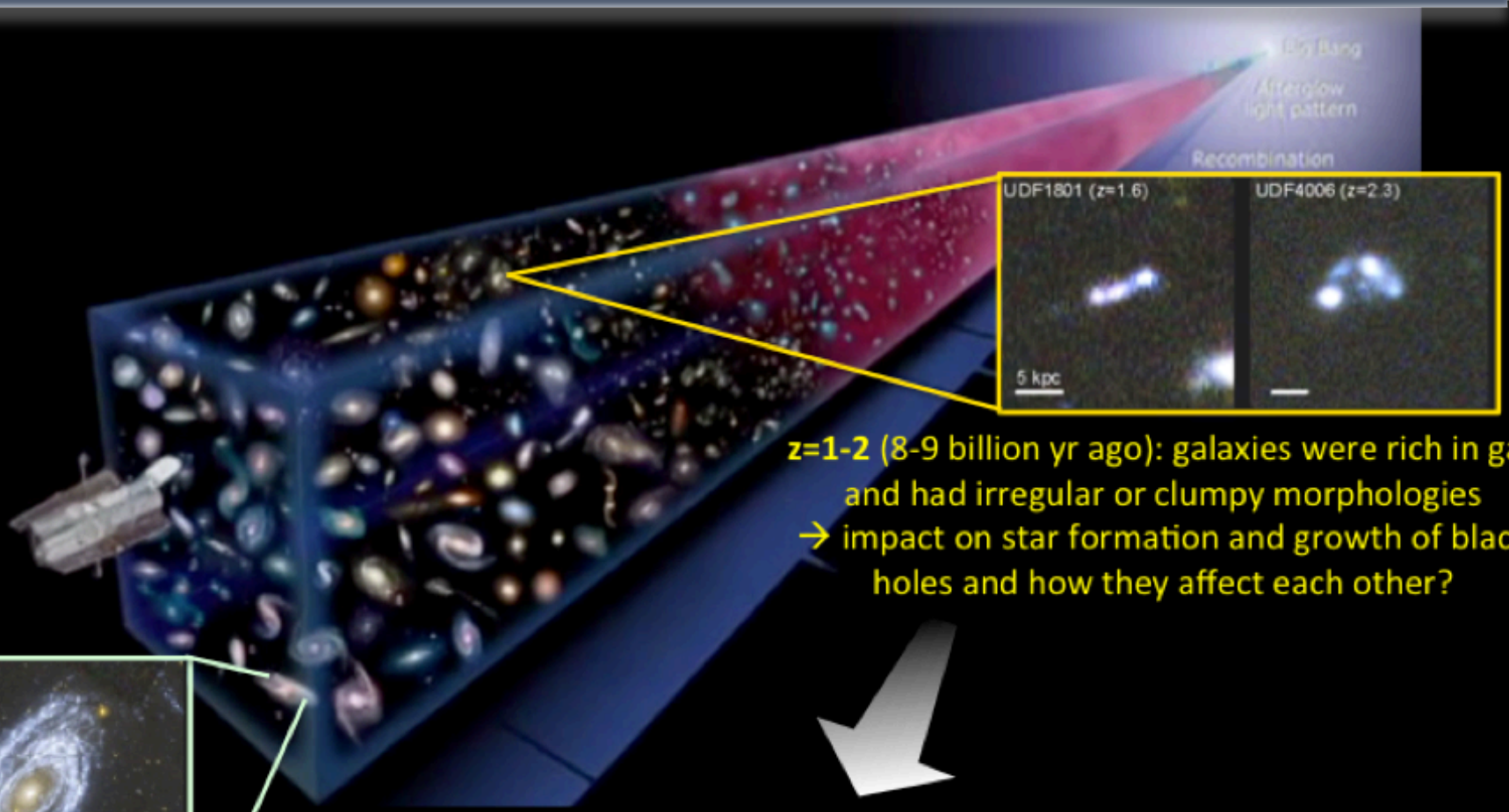
BH-Galaxy Connection

- M-σ relation (e.g., Magorrian+ 1998; Ferrarese & Merritt 2000; Haring & Rix 2004; Lauer+ 2007Lauer+ 2007, Gultekin +2009, McConnell & Ma 2013; but see also Janhke+2011, Kormendy & Ho 2013)
- Similar cosmic growth history: peak at z≈2, decline at later times (e.g. Barger+01, Merloni+04,06, Hopkins+04; Bouwens+10, Madau & Dickinson 2014; Bongiorno +2012)
- Need for negative AGN feedback in cosmological simulations (e.g., Croton+06, Bower +06)

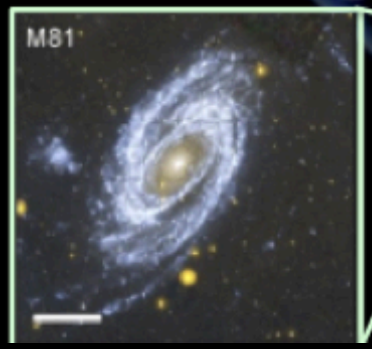


Galaxy Evolution Context

(Image credit: NASA/ESA/A.Feild (STScI)



z=1-2 (8-9 billion yr ago): galaxies were rich in gas and had irregular or clumpy morphologies
→ impact on star formation and growth of black holes and how they affect each other?

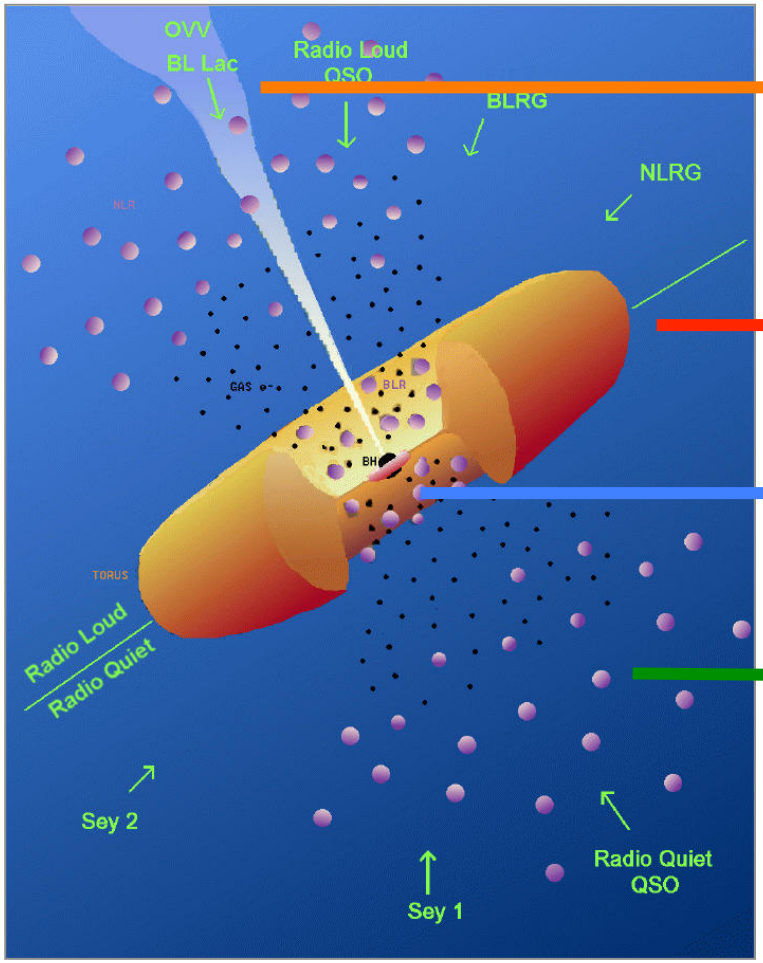


z≈0 (current epoch): galaxies are poor in gas and have regular shapes/morphologies (spiral arms, elliptical, etc.)
→ can only grow stars and black holes at *much lower rates*

Galaxy Evolution Context

- When contrast is an issue → can only detect luminous AGNs in luminous hosts
- More (unstable) gas can mean more absorption of X-rays (e.g., Bournaud et al 2011, 2012)
- High fraction of AGN in clumpy galaxies at z~0.7 (Bournaud et al 2012) and at z~2 (Trump et al 2014, submitted)
- Possible evolution of HII region conditions in galaxies (more extreme source or ISM properties can mimic spectral AGN signatures)
- Evolution of Obscuration Mode (torus vs. host: e.g. Juneau+2013, Donoso+2014)

AGN Unified Model



(Antonucci 1984; Urry & Padovani 1995)

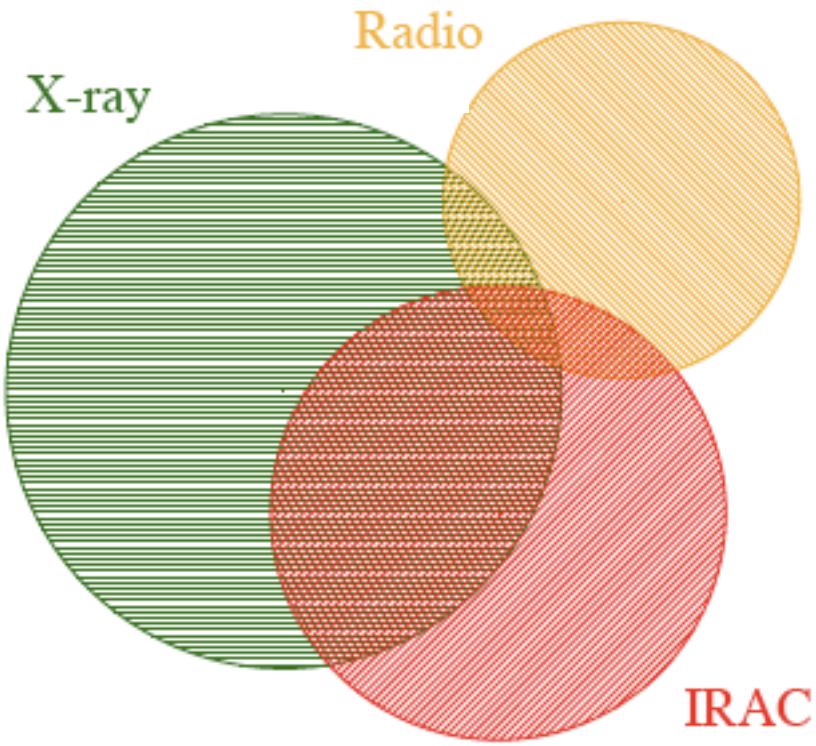
1.4 GHz / FIR
(radio-excess; Del Moro+12)

IRAC colors
(Stern+05; Donley+07; Lacy+04)

$L_X(2\text{-}10keV) > 10^{42}$ erg/s
(Bauer+04)

Narrow Line Regions
(BPT 81, MEx diagram Juneau+11)

Comparison / Overlap



Hickox+ 2009

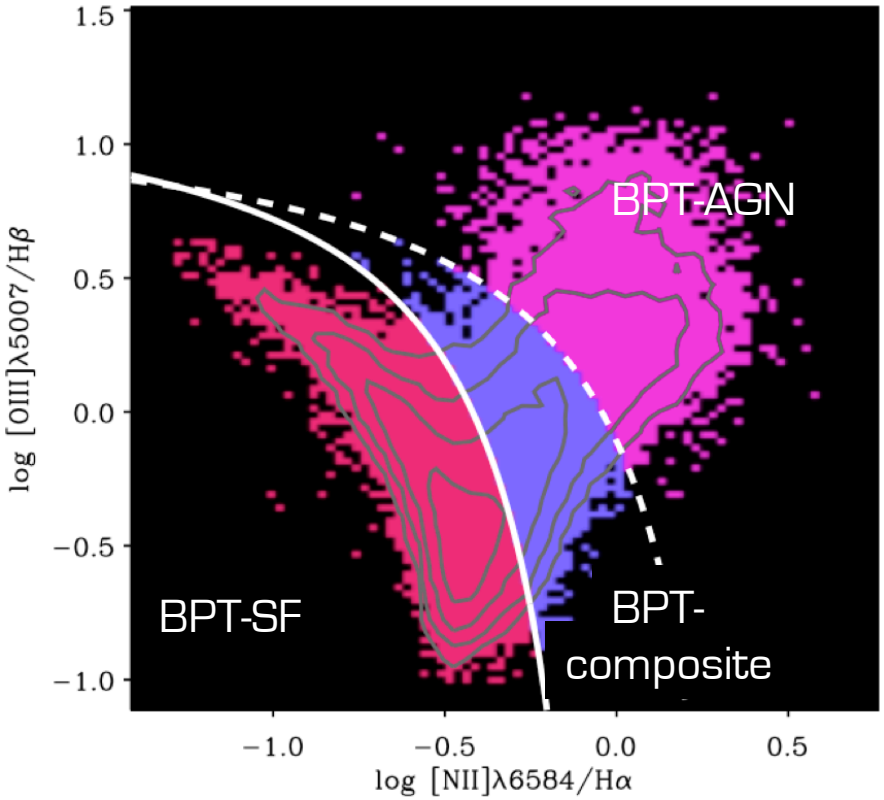
- These AGNs live in different host galaxies!
- →*not* multiple views of the same system
- →different evolutionary paths and/or different points along an evolutionary path? (e.g., Hopkins+2008; Hickox+2009; Alexander & Hickox 2012)

Optical Lines: BPT Diagnostic

(Baldwin, Phillips & Terlevich 81)

1- Empirical & theoretical dividing lines (Kauffmann+ 03, Kewley+ 01, Kewley+ 06)

2- Useable out to $z \sim 0.4$ with optical spectra

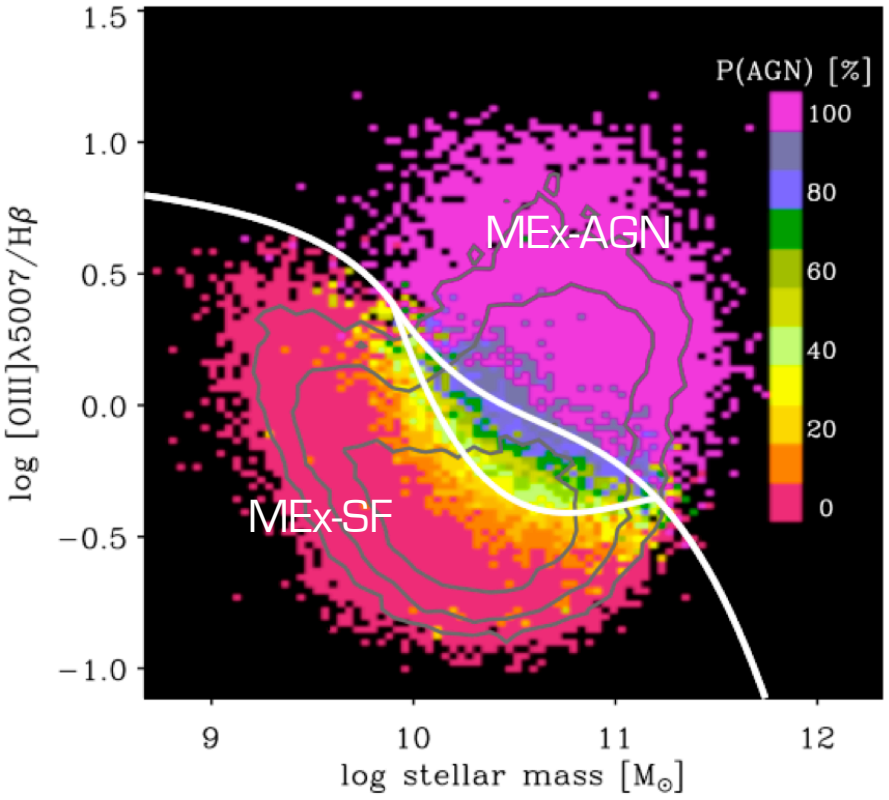


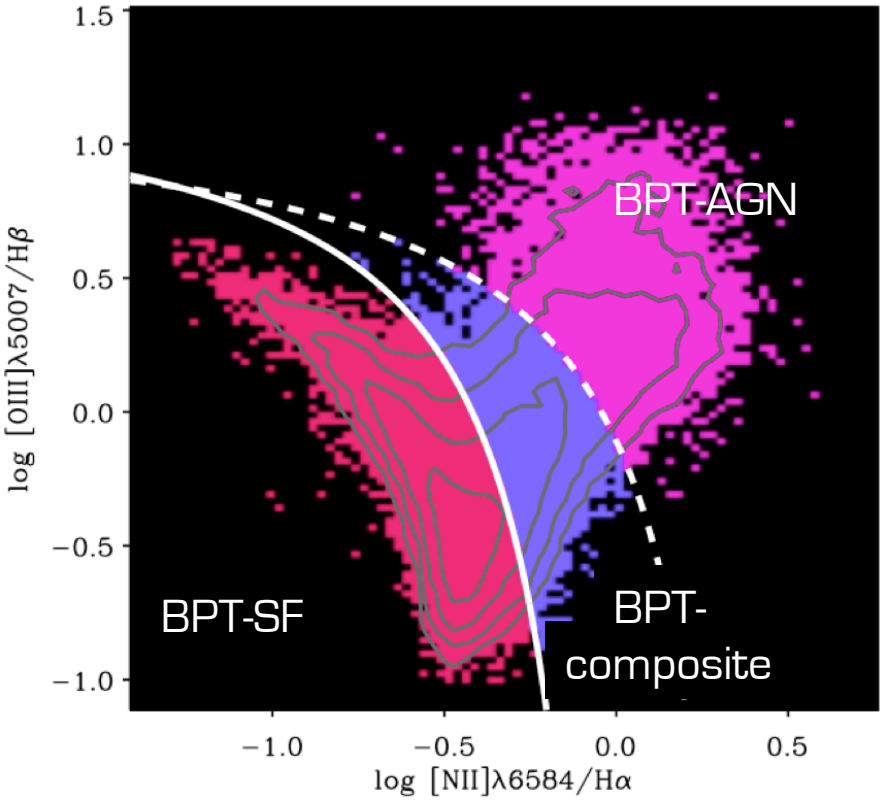
(adapted from Juneau+ 2011)

Mass-Excitation (MEx) Diagnostic

1- Empirical dividing Lines (from >100,000 SDSS galaxies at 0.05<z<0.1)

2- Probabilistic approach → P(AGN) = probability of presence of AGN





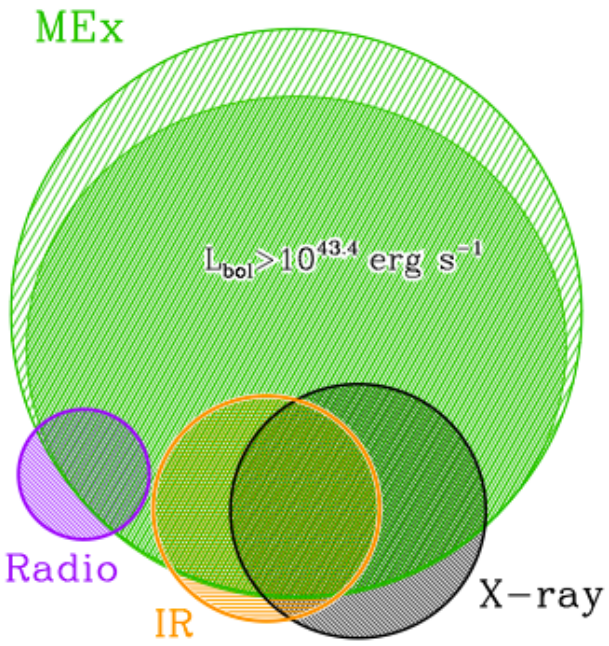
(Juneau+ 2011; tested at z~1.5 by Trump+2013; z~2 by Newman+2014 – UPDATED Juneau+2014)

MEx Diagnostic: Summary

- Calibrated with >10^5 low-redshift SDSS galaxies (0.05 < z < 0.1)
- Consistent with previous studies that found AGN hosts to be massive (e.g., Kauffmann+03, Brusa+09, Mullaney+11) but there may be selection effects (Aird+10, Bongiorno+12)
- Probabilistic approach with built-in uncertainty and applicable as statistical weights
- Tested directly up to z=1 with independent X-ray data (detections and stacking; Juneau+2011) and up to z=1.5 with NIR spectra (Trump +2013)
- **Don't we expect evolutionary effects?** (e.g., Kewley+13a,b; Newman+14; Holden+14; Juneau+14)

AGN Identification

- **X-ray** ($L_X > 10^{42}$ erg/s *or* HR > -0.1; similar to Bauer+04)
- **Optical emission lines** (MEx diagram; Juneau+ 11)
- **IRAC colors** (Stern+ 05, but also see Lacy+04,07, Donley+07,12)
- **Radio-excess** (Sargent+ 10; Del Moro+ 12)



3 AGN Categories

- X-ray unabsorbed AGN (L_X(2-10keV) > 10^{42} erg/s)
- X-ray absorbed AGN (infer L_X > 10^{42} erg/s from [OIII])
- weak AGN (L_X <10^{42} erg/s intrinsically)

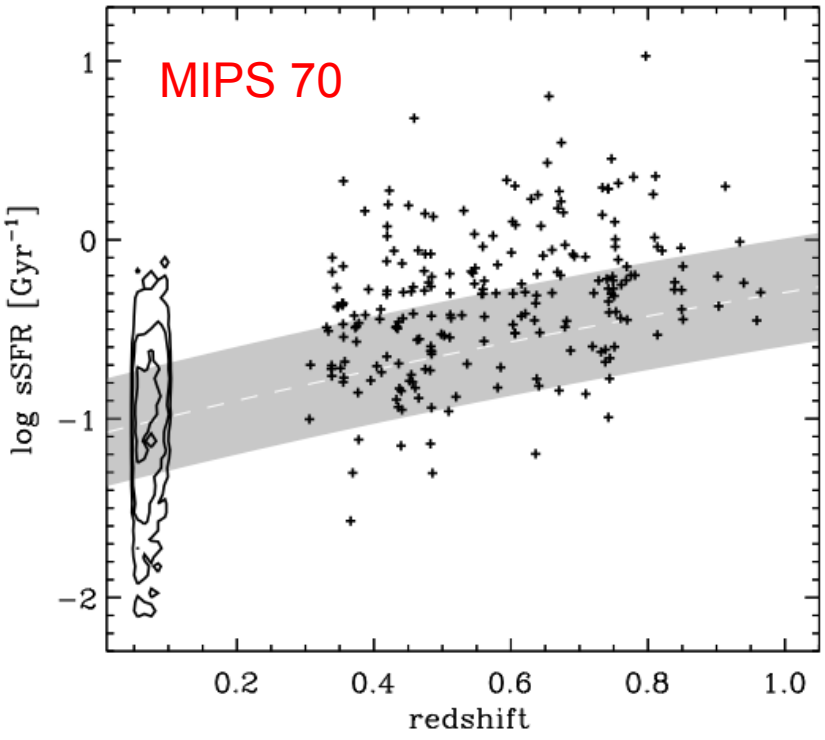
Missed in deepest X-ray surveys
(e.g., 2 Msec *Chandra* Deep Field North)

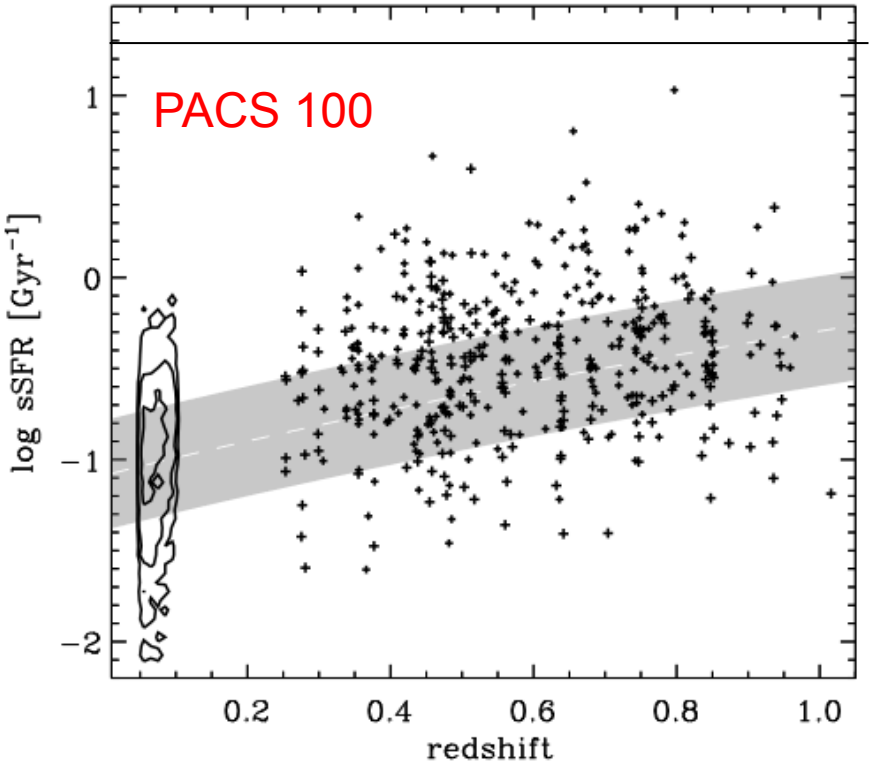
Note: The X-ray absorption is *inferred* and not measured.

AGN in Star-Forming Galaxies

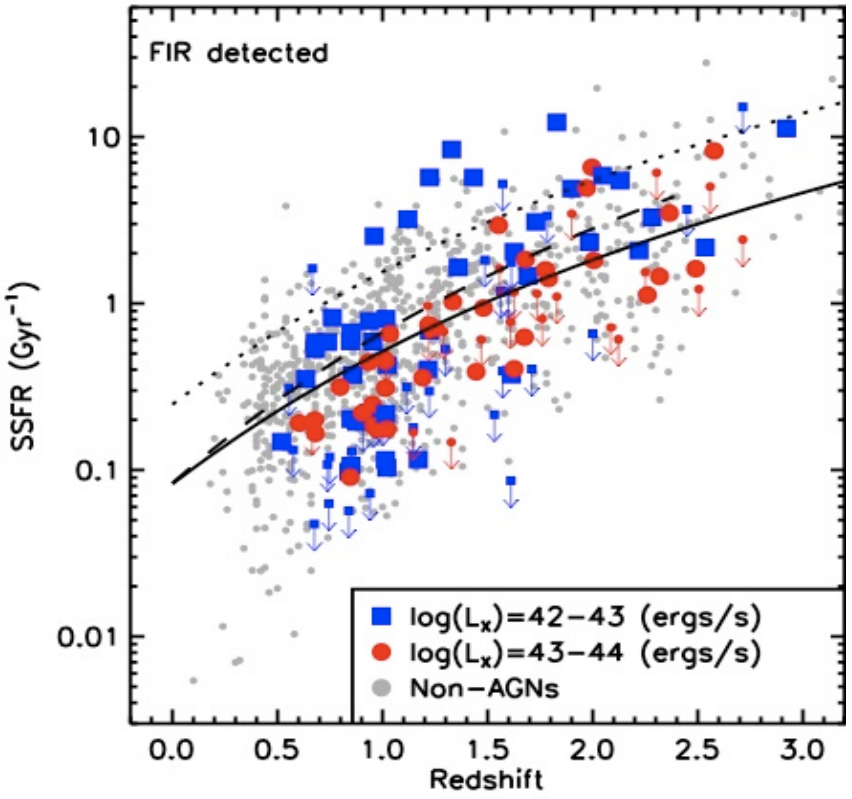
- Selection from the **F**ar-**I**R **D**eep **E**xtragalactic **L**egacy survey (**FIDEL**, PI: M. Dickinson; catalog in Magnelli+2011) in EGS 2.5mJy (3σ) with *Spitzer*/MIPS70 (Juneau+ 2013)
- Herschel/PACS 100-selected sample in GOODS-N (in prep.)

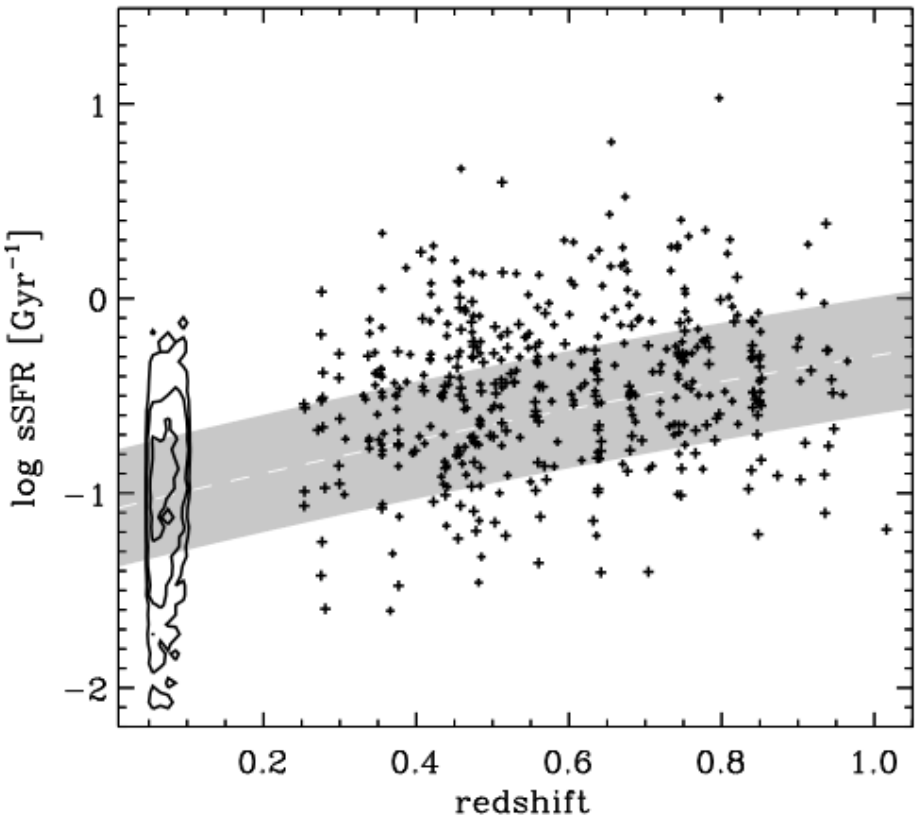
→ typical star-forming galaxies → major contributors to the cosmic star formation rate; e.g., Le Floc'h+ 2005, Magnelli+ 2009)





AGN on the sSFR sequence

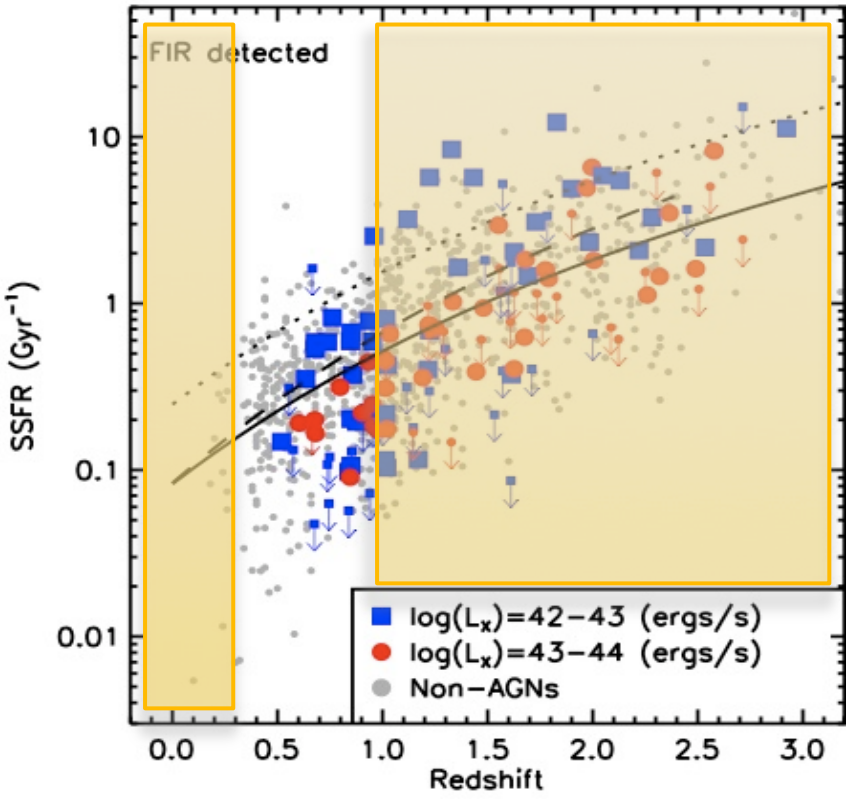


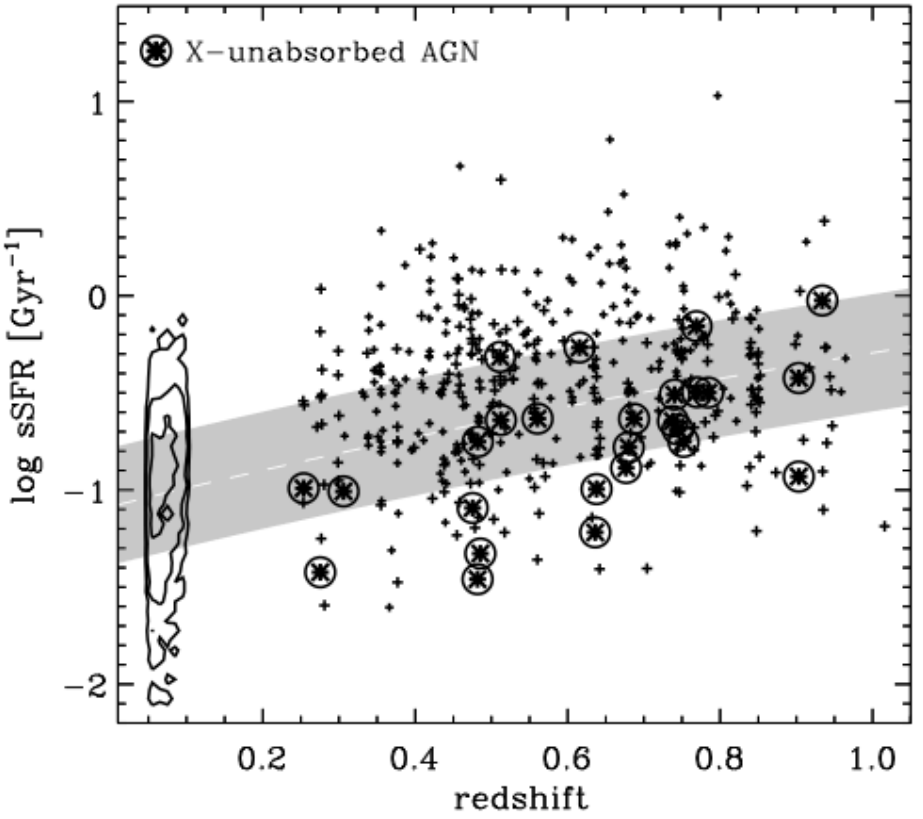


X-ray selected AGN: 10% of MS galaxies

(Mullaney et al. 2011)

AGN on the SSFR Sequence





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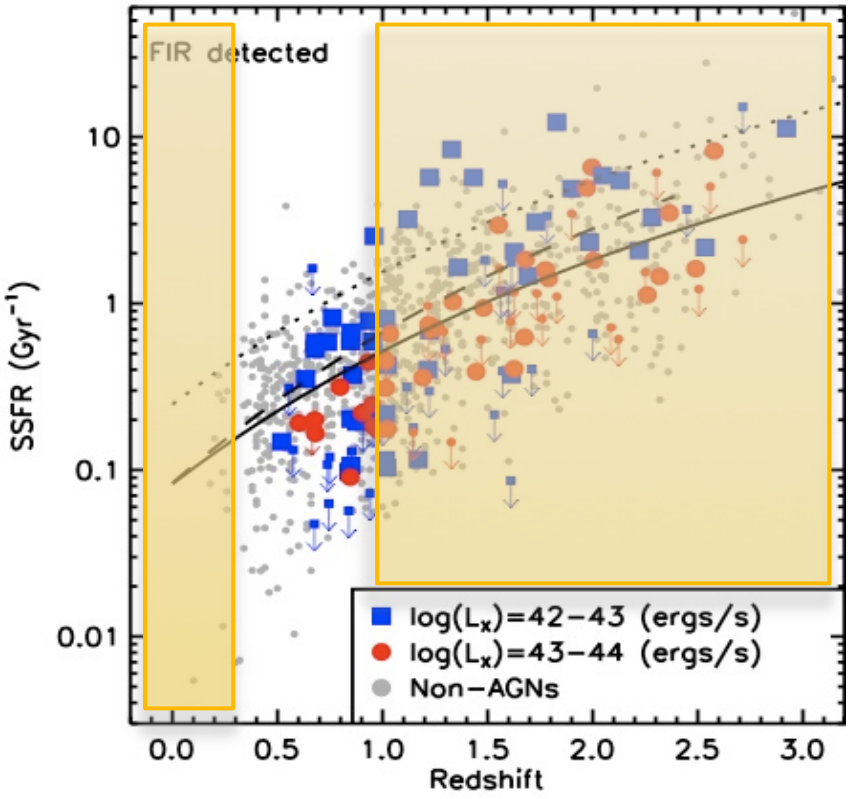
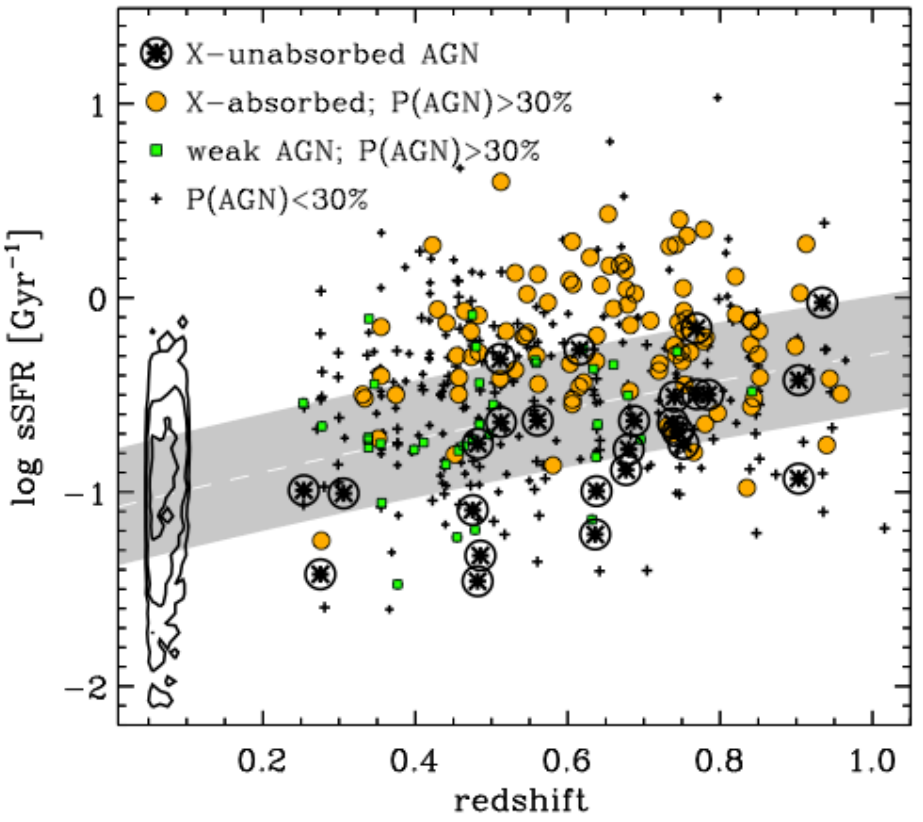
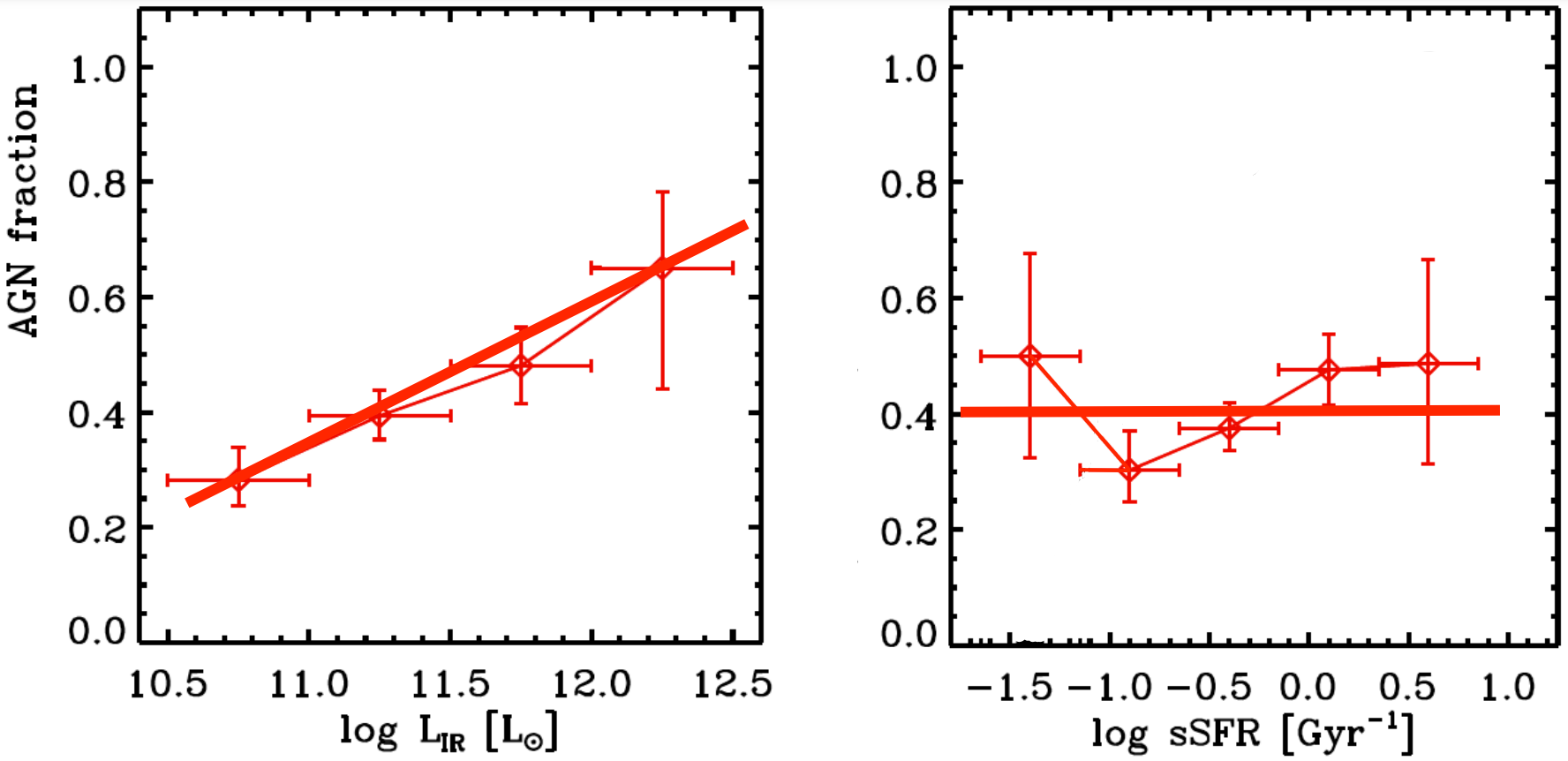




f(Star Formation Rate)

f(SSFR = SFR/M_*)

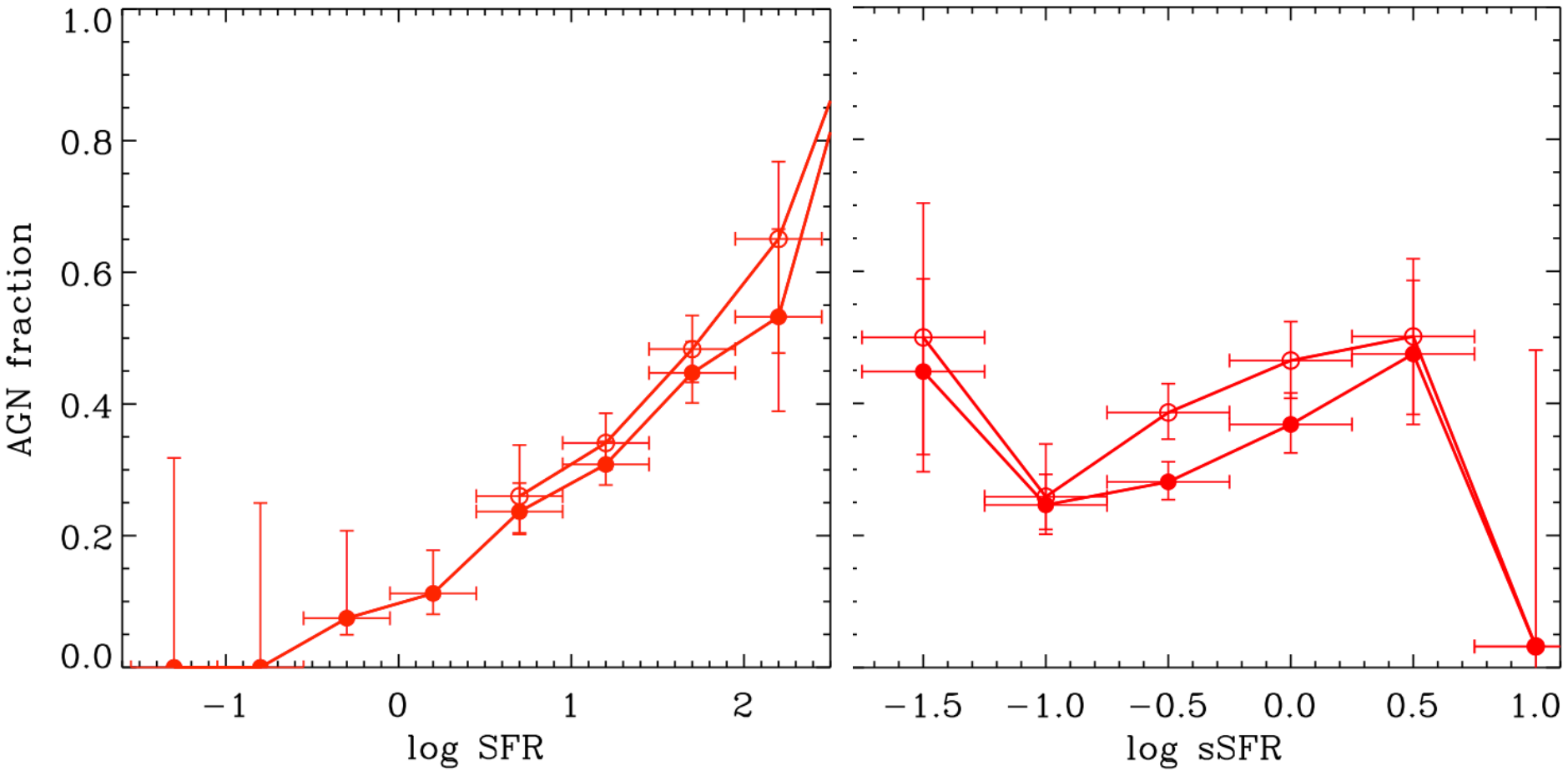


0.3<z<1 galaxies that were selected from MIPS70

→ AGN triggering cares about SFR (~gas mass) but not as much about SSFR (~gas fraction)

Juneau et al. 2013

f(Star Formation Rate) f(SSFR = SFR/M_*)



Comparing MIPS70 sample (open circles) and new PACS100 sample (filled circles)

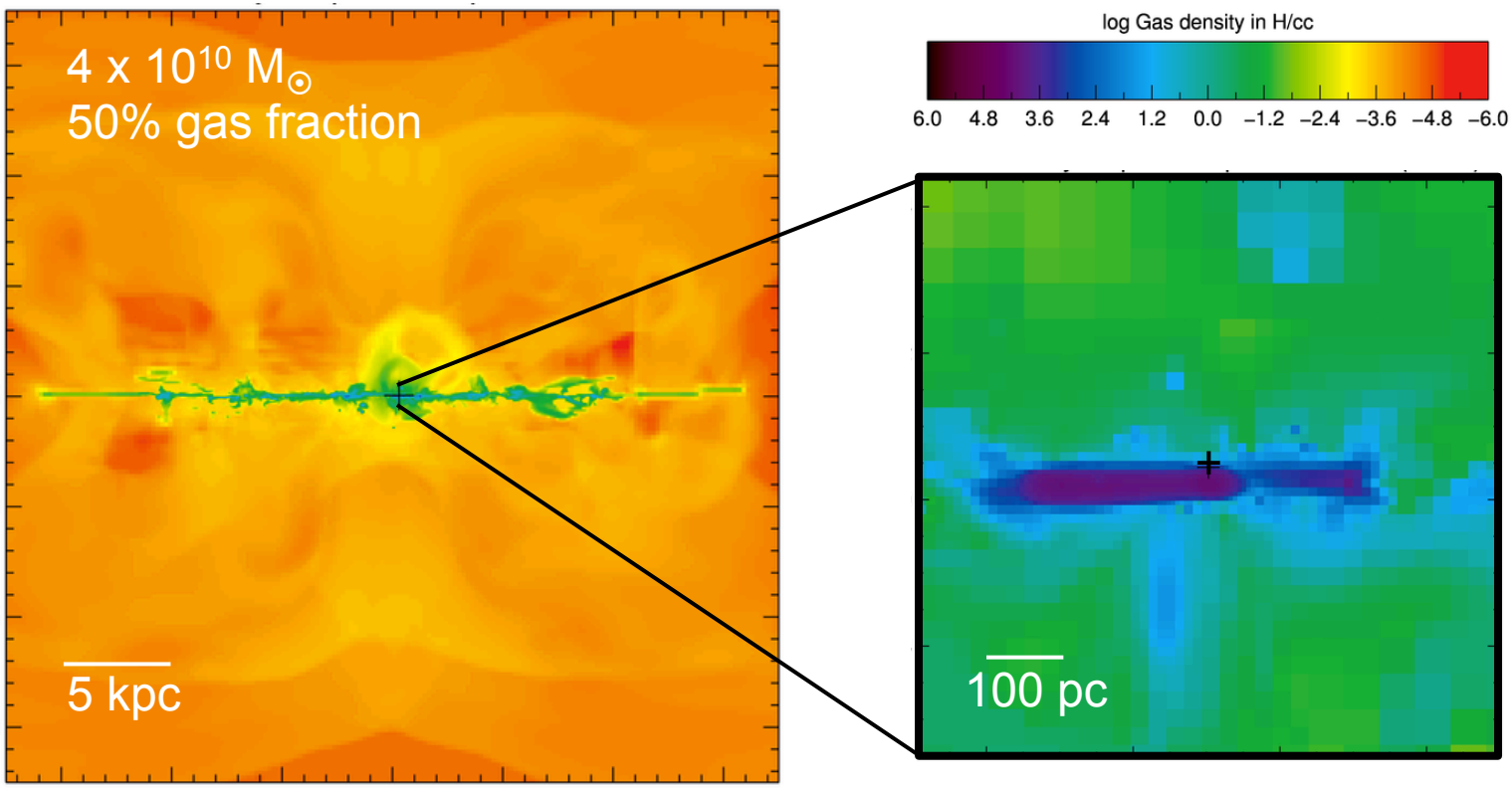
(in prep)

Summary

- High incidence of AGN in *star-forming* galaxies (30-37%; Juneau+13)
  - Similar to low-z sample f(SFR) → higher AGN fraction at high z
- Common triggering mechanisms for star formation and AGN
  - Higher duty cycle revealed with multi-wavelength AGN identification!
  - Clumpy/Unstable disks effectively fuel AGN (Bournaud+11,12; Trump+14 in press)
- AGN Triggering knows about host SFR *and* Stellar Mass
  - Future work required to control for selection effects
- Concurrence is very common: How about AGN Feedback?
  - AGN-driven outflows is disks (Gabor talk)
  - Effect of AGN photoionization on SF (Roos+14: **arXiv 1405.7971**)

Feedback

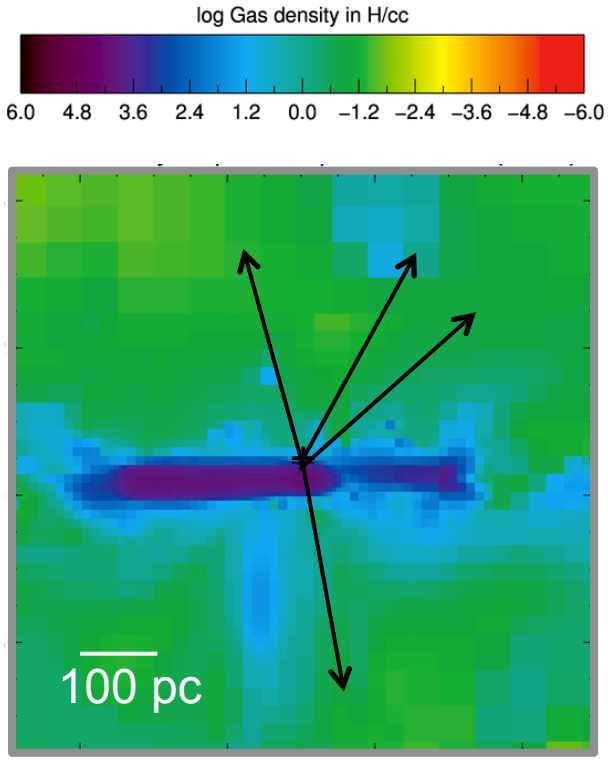
- AMR simulations w/ thermal feedback (Gabor+2013, 2014)
- Add AGN photoionization (Orianne Roos; CEA-Saclay)



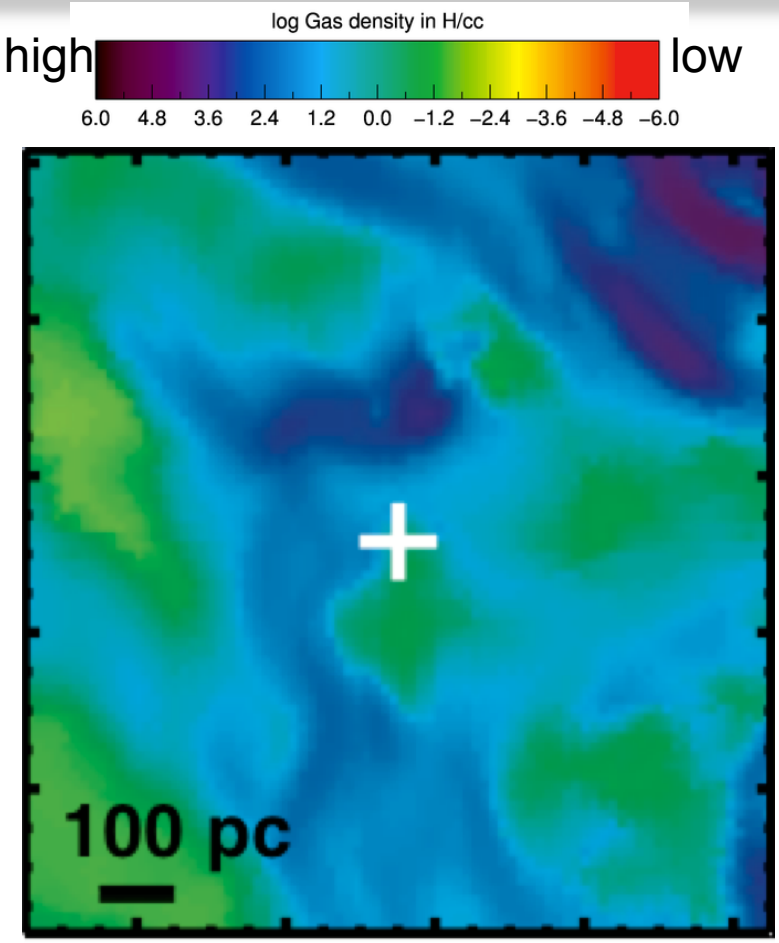
Feedback

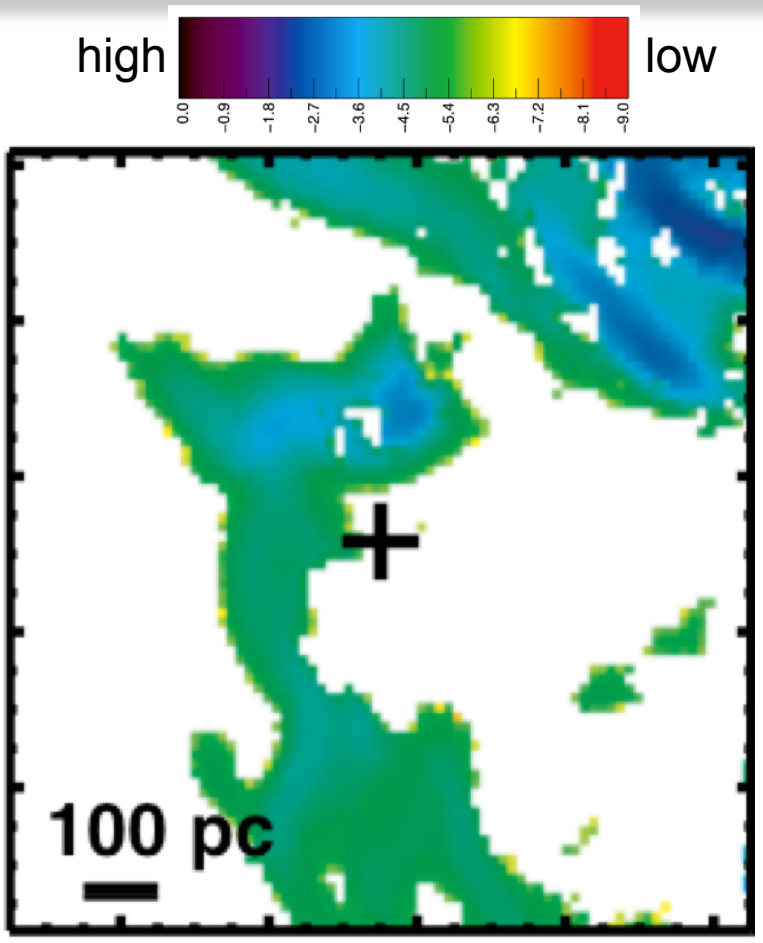
- AMR simulations w/ thermal feedback (Gabor+2013, 2014)
- Add AGN photoionization (Orianne Roos; CEA-Saclay)

- Draw lines of propagation from BH location
- Radiative transfer with Cloudy (Ferland+2013) with realistic AGN spectra (Seyfert to Quasar luminosities)



n_H [cm^{-3}] ρ_{SFR} [$M_\odot$ yr^{-1} pc^{-3}]





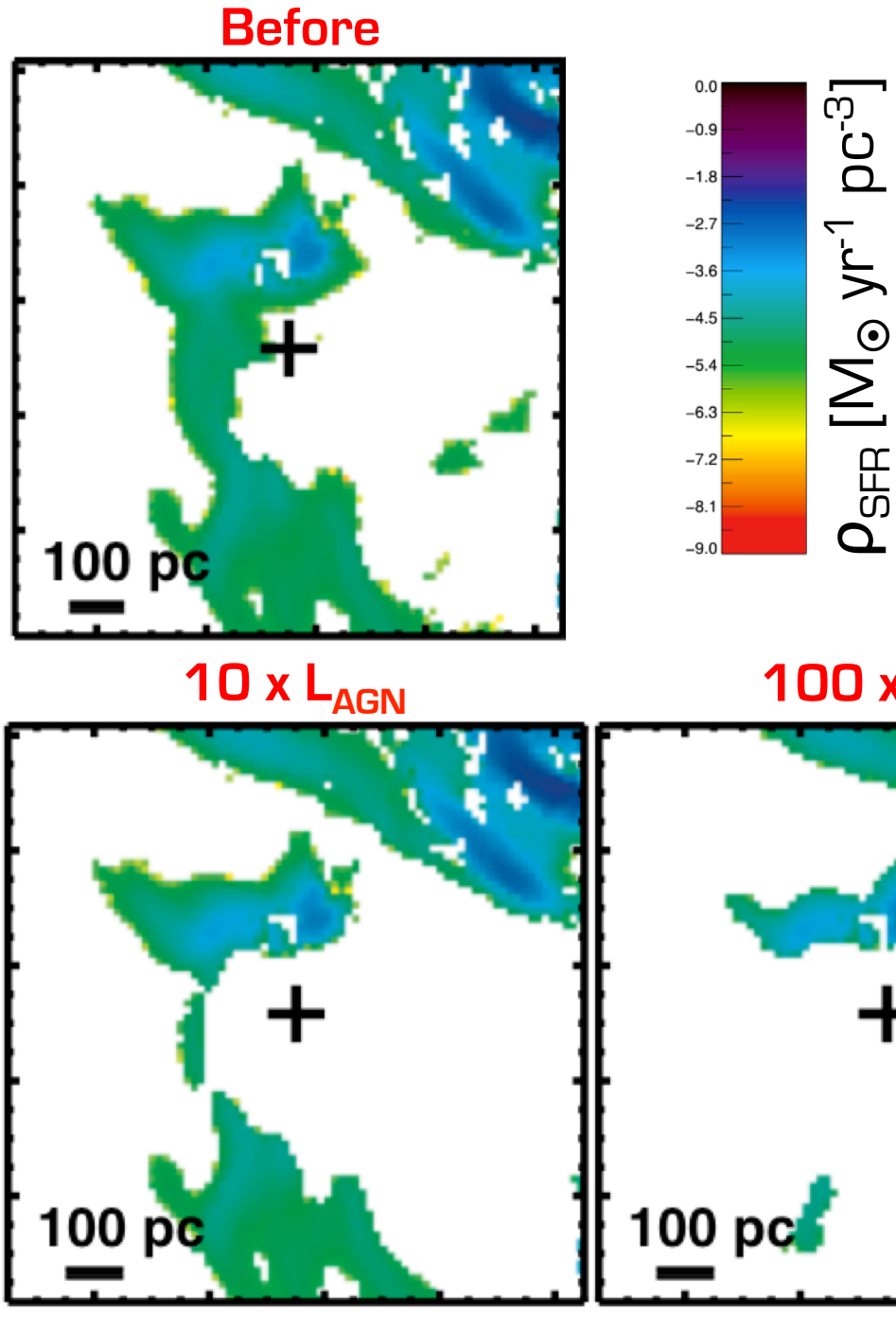
Criteria for SF: $n_H > 10$ cm^{-3} and $T<10^4$ K

Roos et al. 2014: **arXiv 1405.7971**

Roos et al. 2014

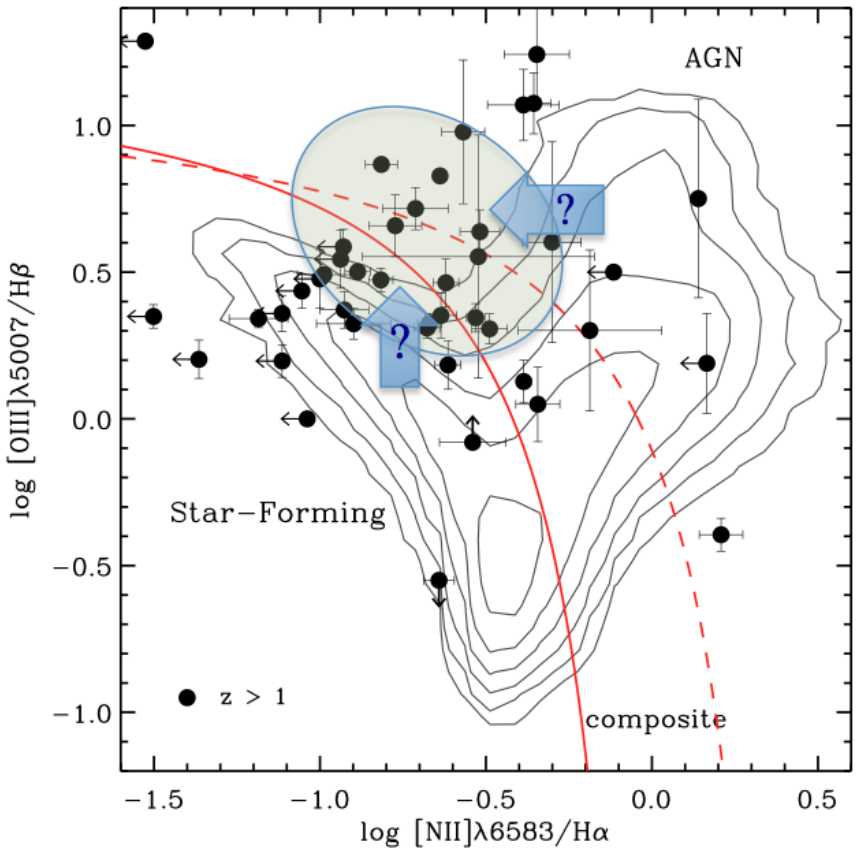
arXiv 1405.7971

See Poster!



Thank You

BPT diagnostic at higher redshifts

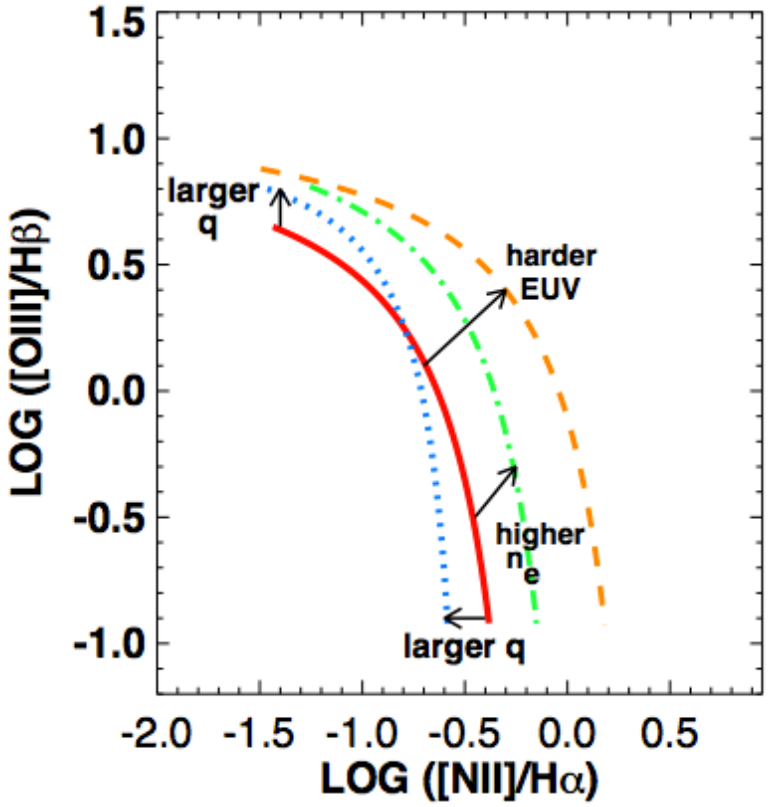


Offset between high-redshift (1<z<3) galaxies and low-redshift locus on BPT diagram

- Changing HII region conditions? (higher n_e, T_e, P, Σ_{SFR}; Liu+08, Brinchmann+08, Lehnert+09)
  → mode of SF
- Changing AGN contribution? (Groves +06, Wright+10)
  → AGN incidence or duty cycle
- Can we predict/understand this behavior from low-redshift analogs?

[+see Kewley's talk]

BPT diagnostic at higher redshifts



Kewley+ 2013a

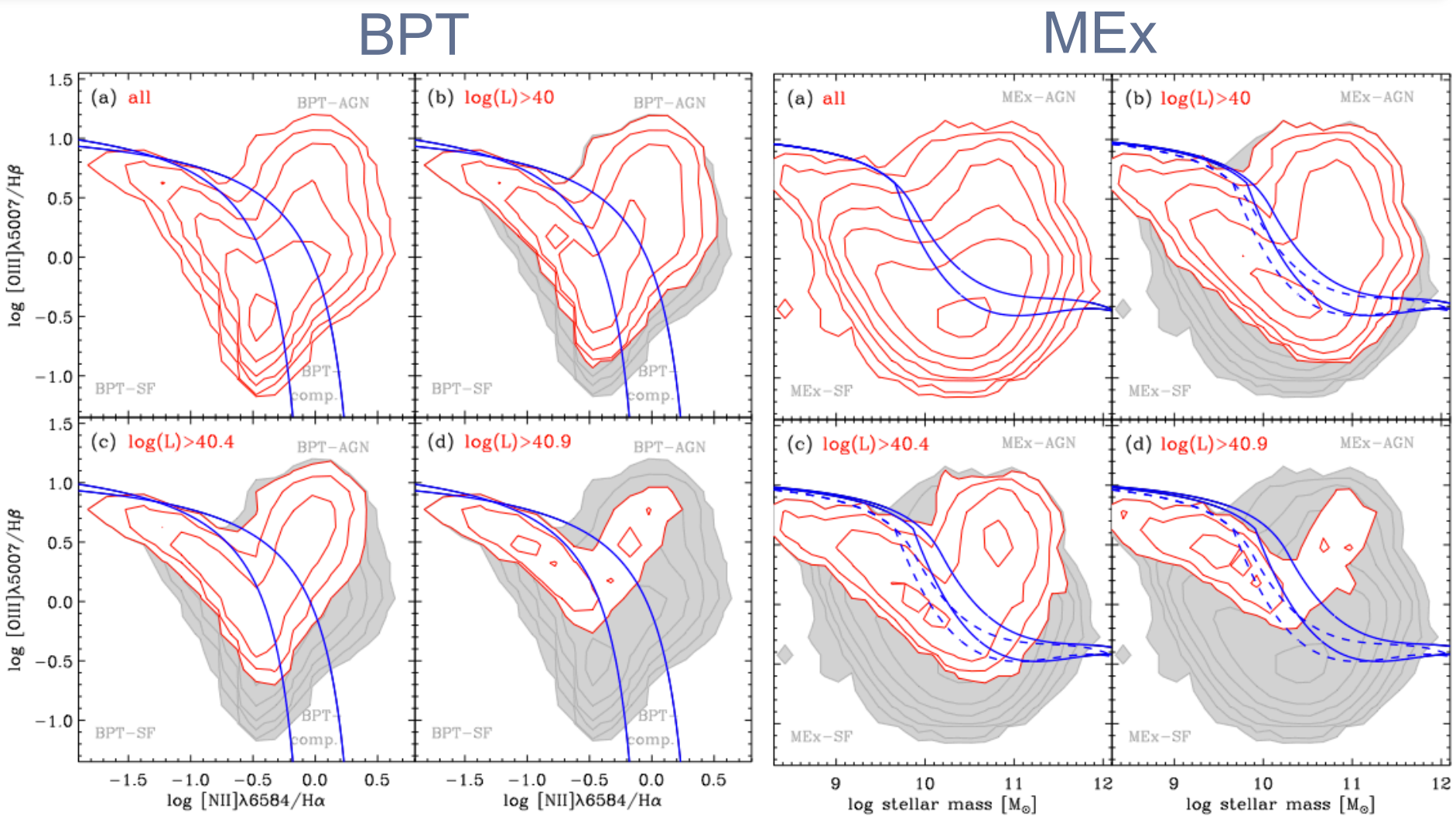
- Changing HII region conditions?

→ Theoretical predictions based on stellar population and photoionization models (e.g., Kewley + 2013a)

→ Potentially important impact to get self-consistent treatment of stellar emission and gas emission is galaxies (e.g., Pacifici+2012) and to properly identify AGN

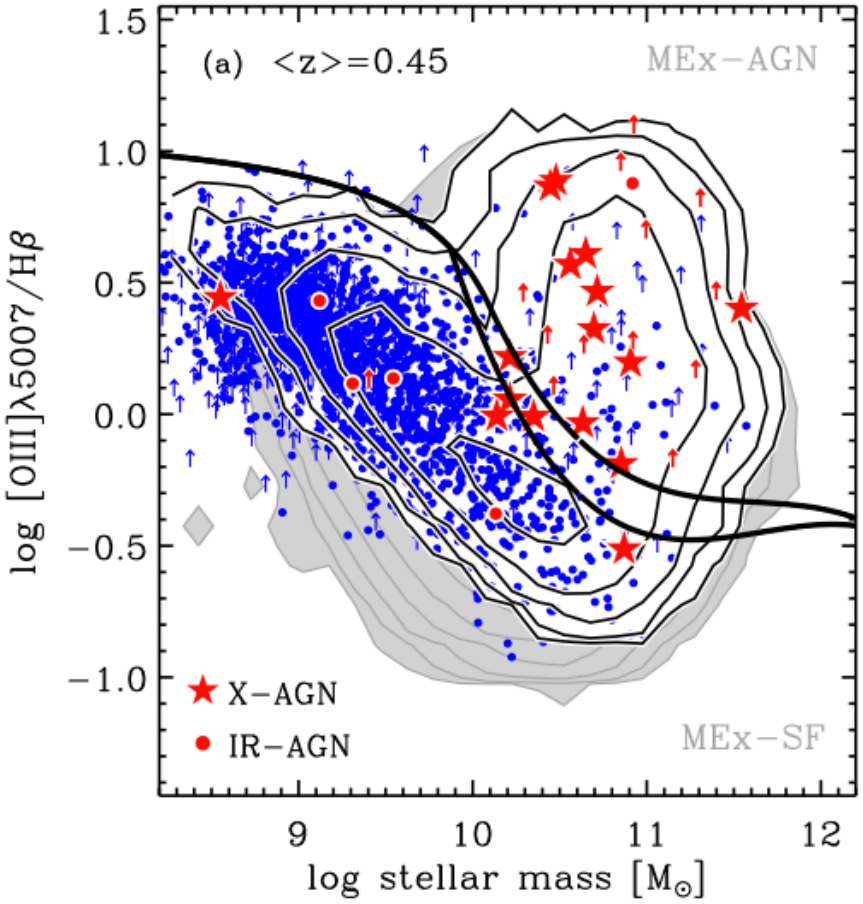
(also Baldwin+81, Veilleux+87, Kewley+01, Kauffmann+03, Stasinska+06; Kewley+06)

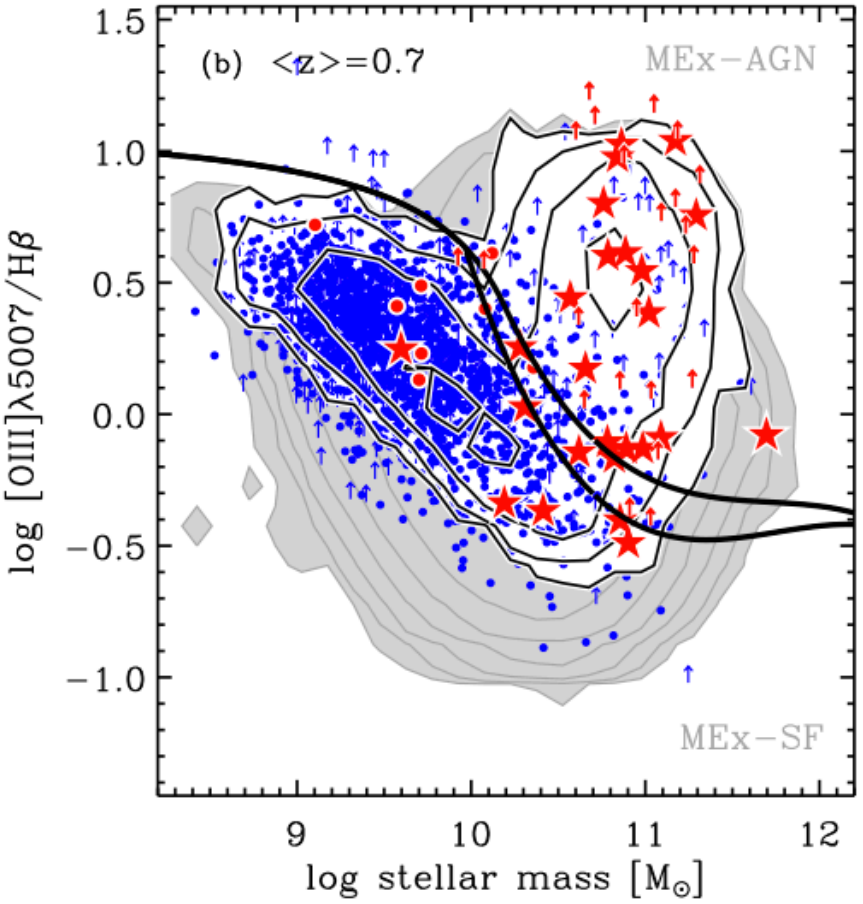
Emission-line Luminosity Threshold



Juneau et al, 2014

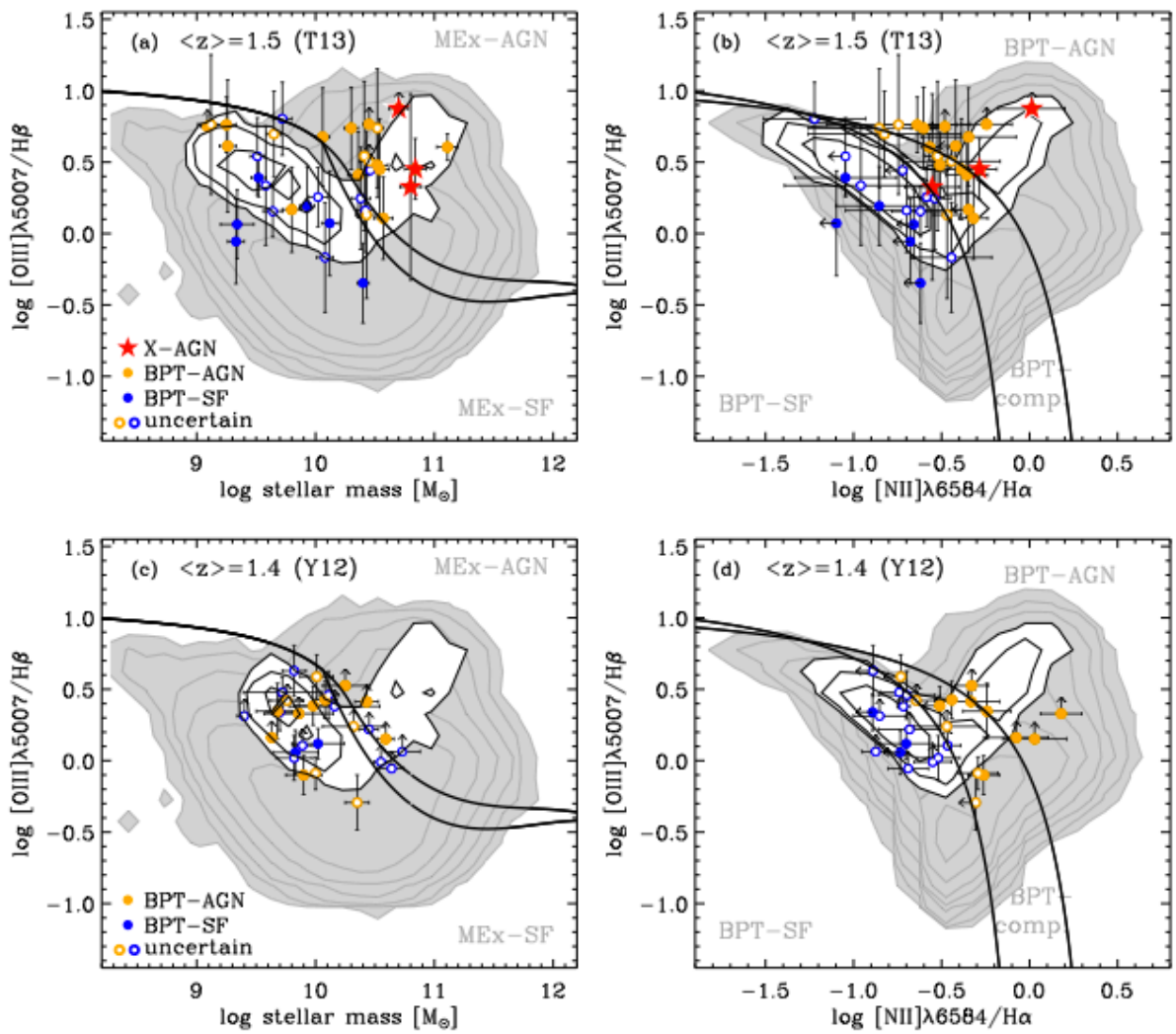
Application at 0.3 < z < 1





Juneau et al, 2014

Application at z =1.5

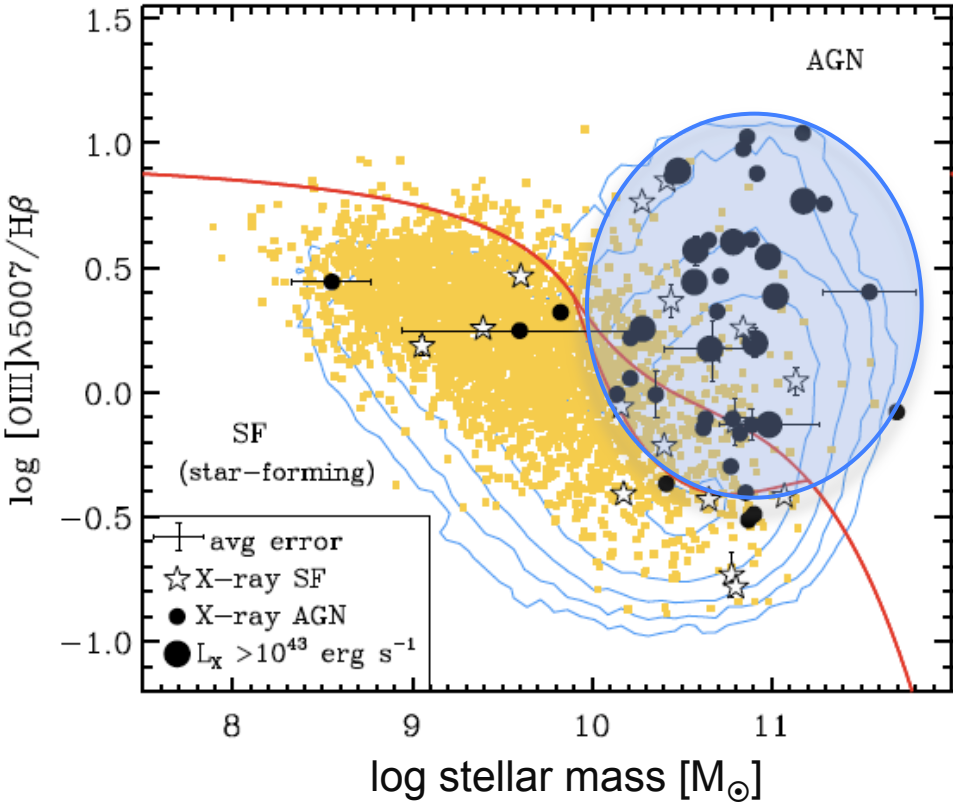


Juneau et al, 2014

MORE ON MEx

MEx confirmed with X-rays

Mass-Excitation (MEx) diagnostic



- MEx diagram identifies 85% of X-AGN that have emission lines

Sample: 3,386 galaxies at **0.3<z<1** with [OIII]λ5007, Hβ & stellar mass in **GOODS-North** & **EGS**
Chandra X-ray: 2 Msec in GOODS-N (Alexander+ 03); 200 ksec in EGS (Nandra+05, Laird+09)

Juneau et al. 2011

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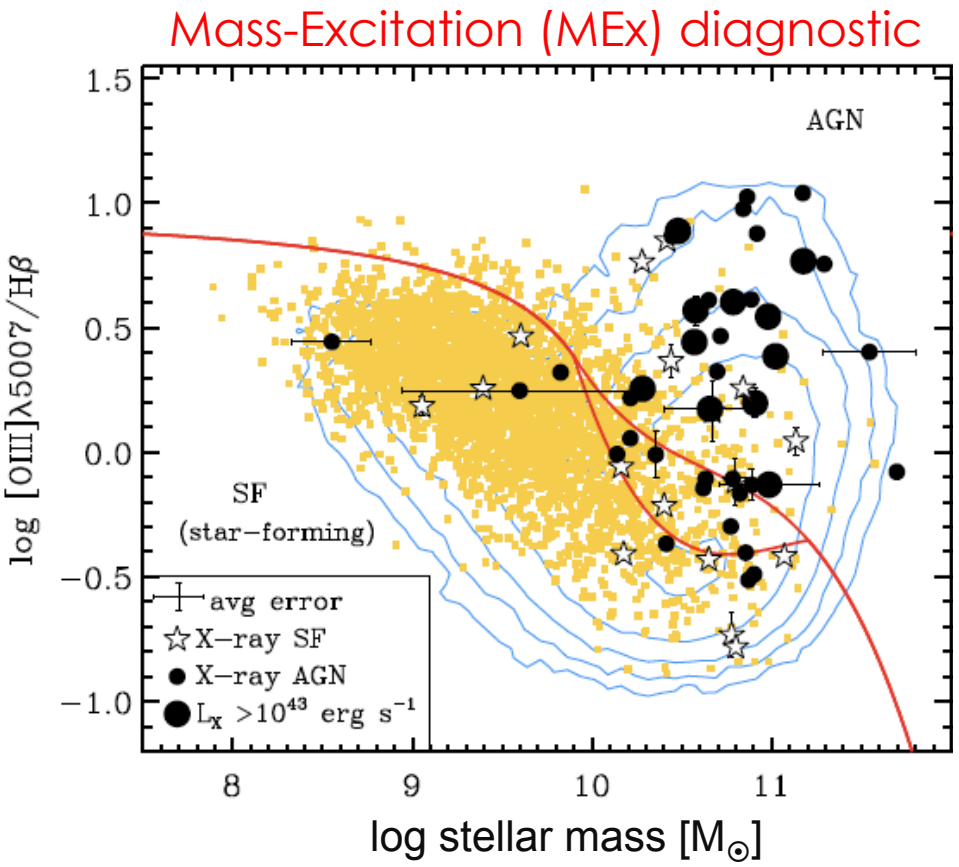

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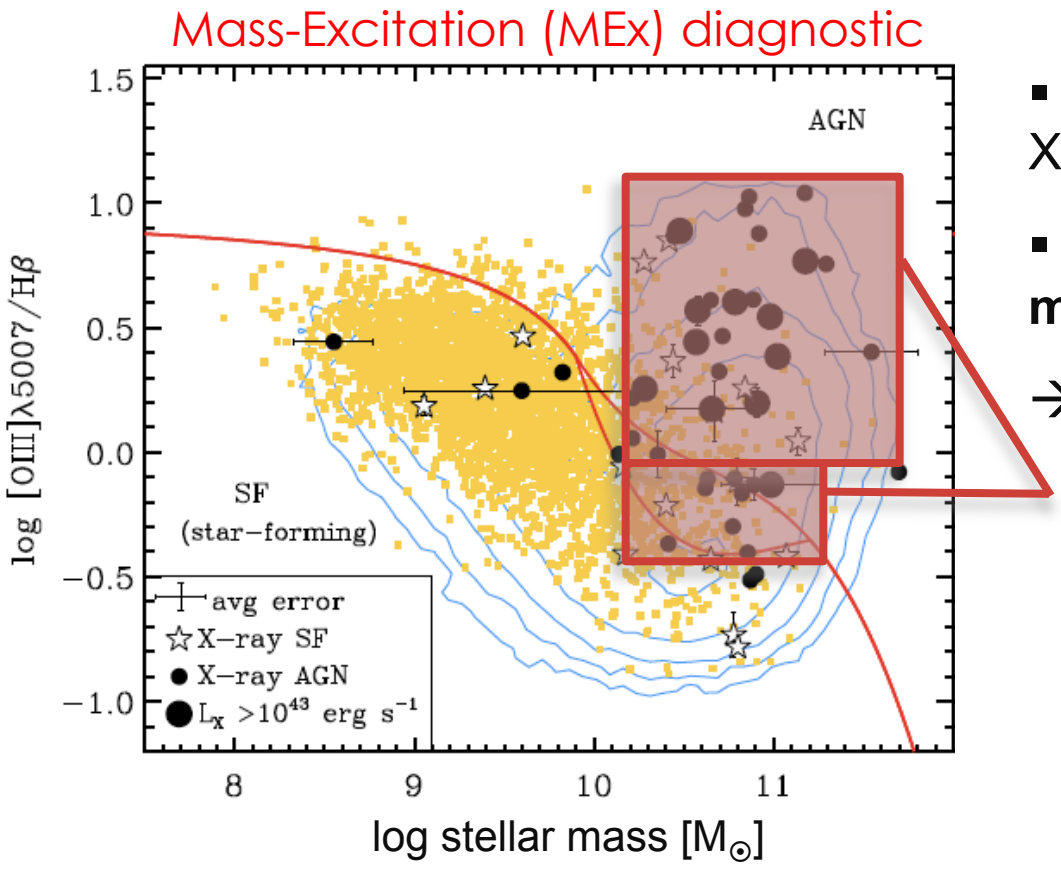

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→ **X-ray stacking**

MEx-AGN
- *Chandra*'s soft & hard bands yield a flat X-ray spectral index (Γ~0.6): **some obscured AGN!**

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- Only soft band detection: **consistent with SF**

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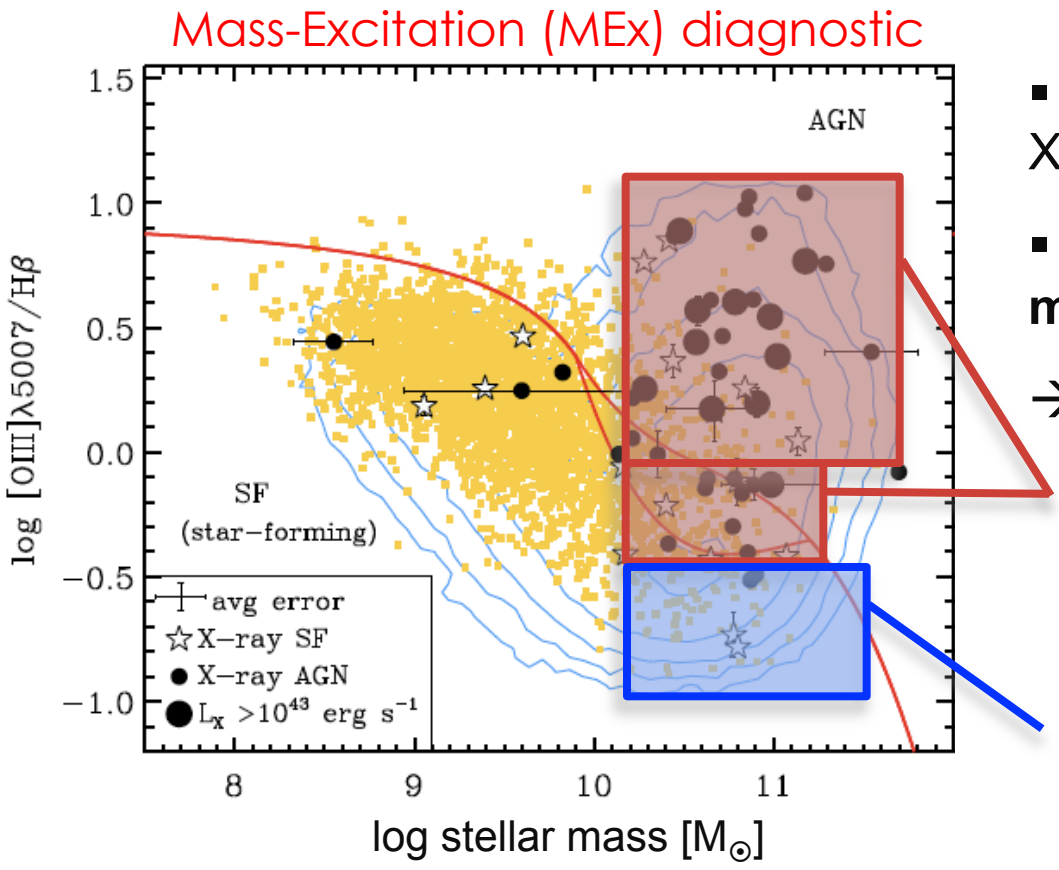

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