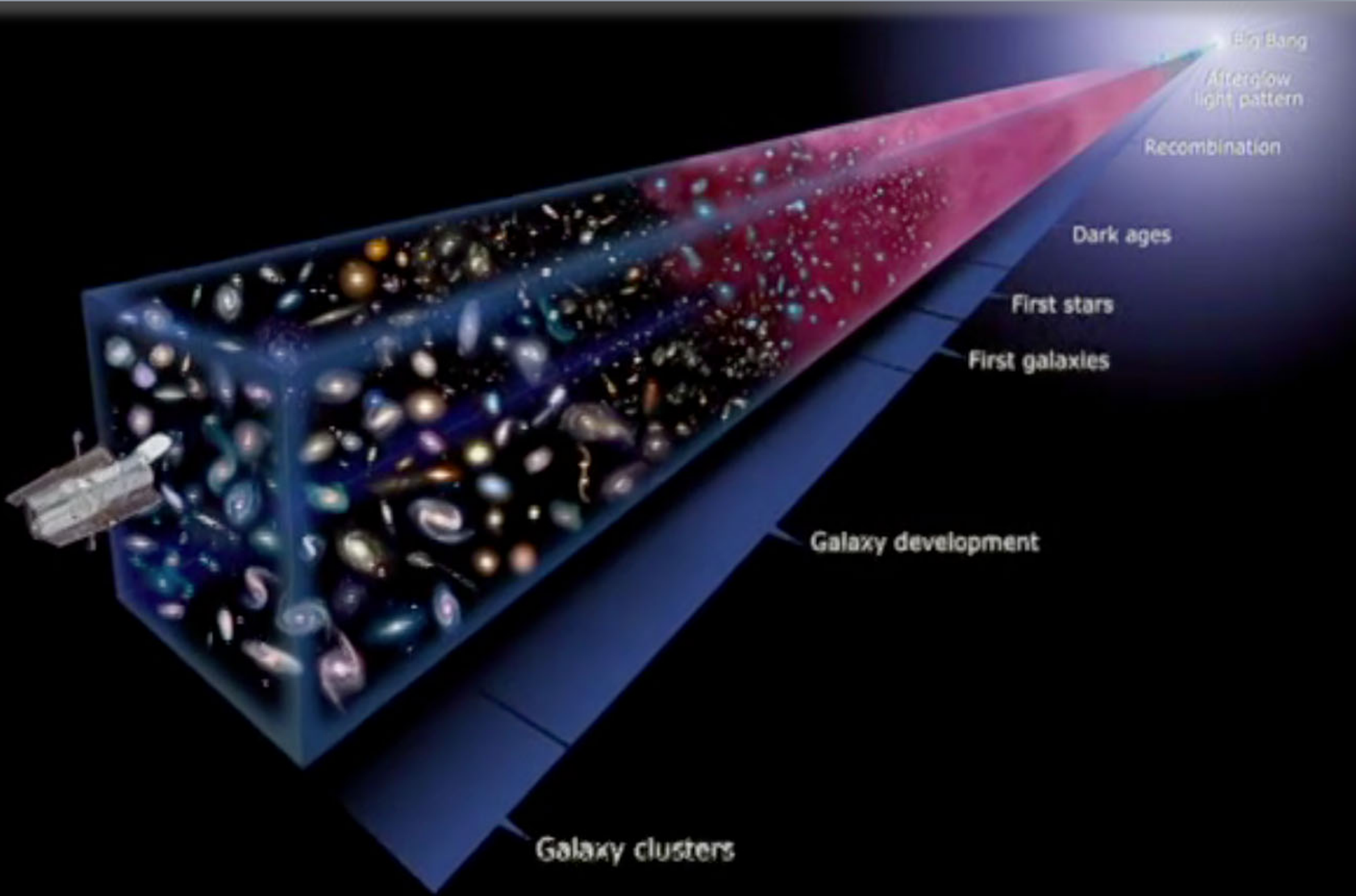
Identifying Black Holes in an Evolving Galaxy Population

Stéphanie Juneau

CEA Saclay

Collaborators: Stéphane Charlot (IAP), Orianne Roos (CEA), Frédéric Bournaud (CEA), Jared Gabor (CEA), Elisabete da Cunha (CAS), Michaela Hirschmann (IAP), Mark Dickinson (NOAO), Matt Lehnert (IAP), Emanuele Daddi (CEA), Jon Trump (PSU), David Elbaz (CEA) and ++ (GOODS & AEGIS teams)

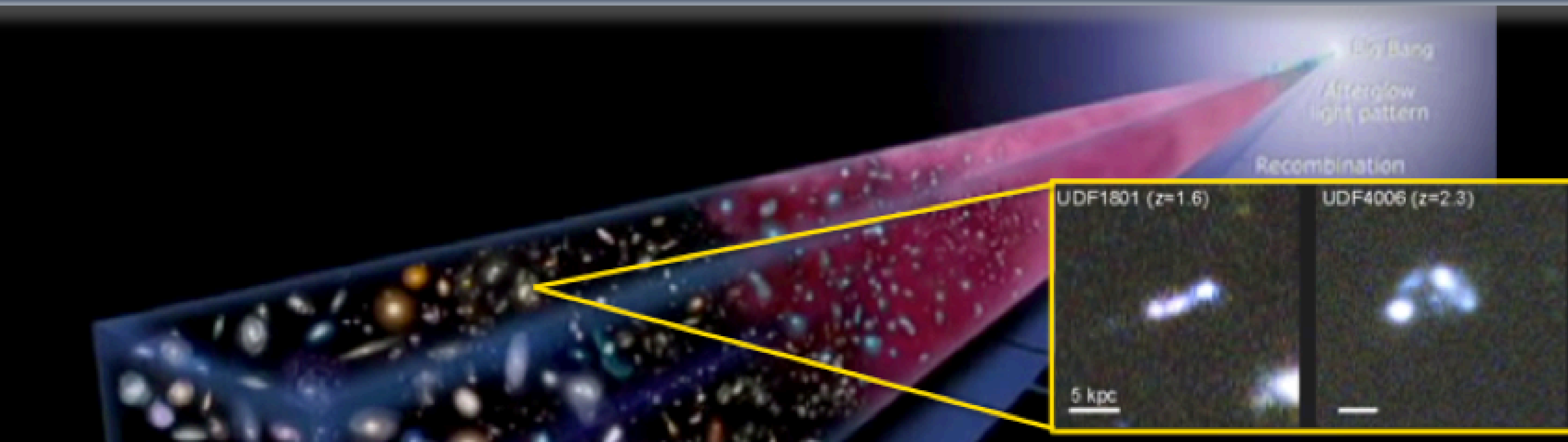
Context



Big Bang
Afterglow light pattern
Recombination
Dark ages
First stars
First galaxies
Galaxy development
Galaxy clusters

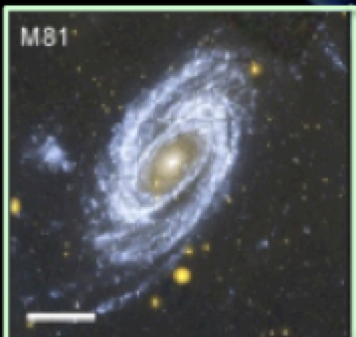
Context

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



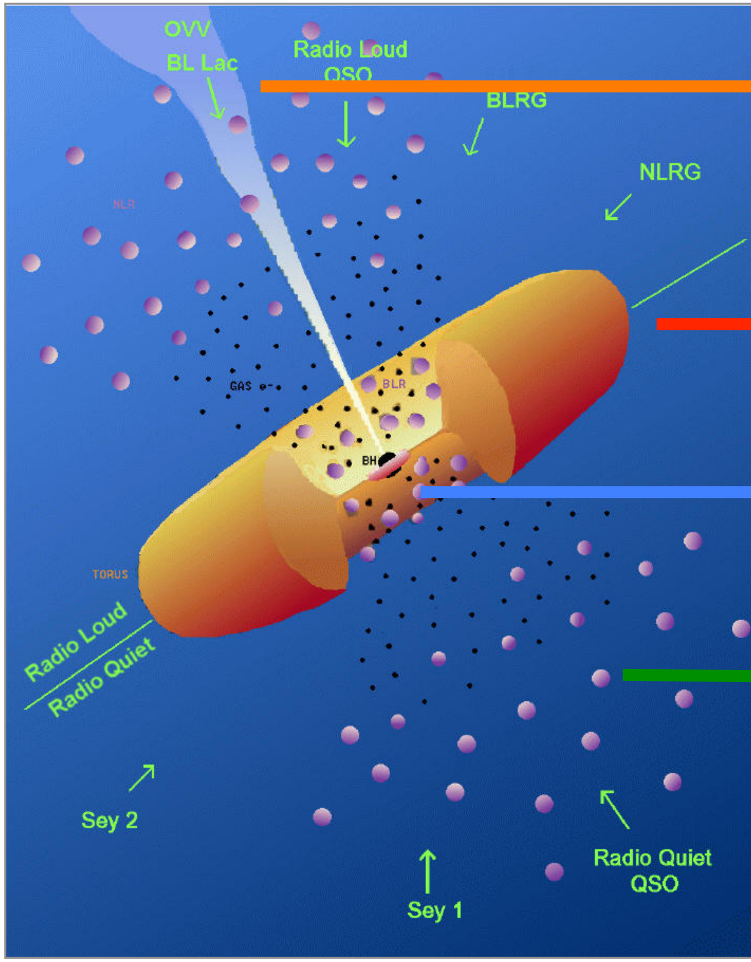
z=1-2 (8-9 billion yr ago): galaxies were rich in gas and had irregular or clumpy morphologies
→ impact on star formation and growth of black holes and how they affect each other?

How does the BH-galaxy link evolve through time?



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*

AGN Unified Model



(Antonucci 1984; Urry & Padovani 1995)

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

IRAC colors
(Stern+05; Donley+07)

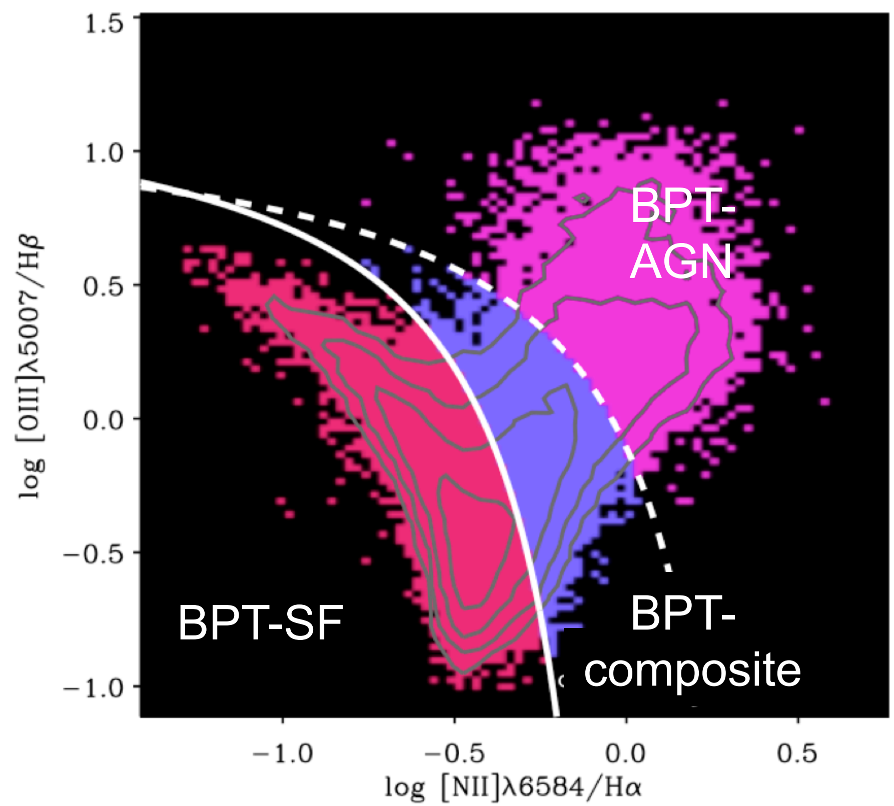
L_X(2-10keV) > 10^{42} erg/s
(Bauer+04)

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

BPT Diagnostic (Baldwin, Phillips & Terlevich 81)

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

2- Useable out to z~0.4 with optical spectra

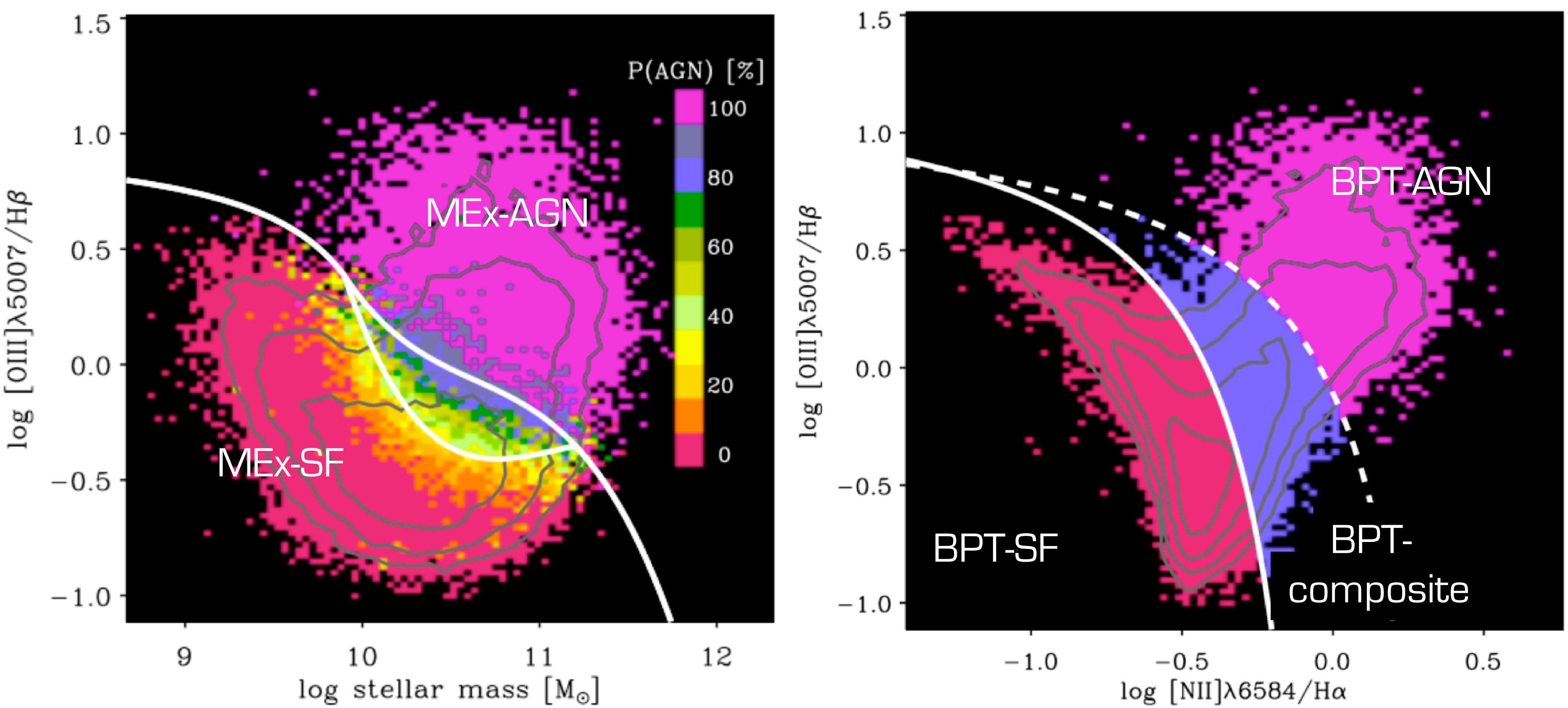


(adapted from Juneau+ 2011)

Mass-Excitation (MEx) Diagnostic

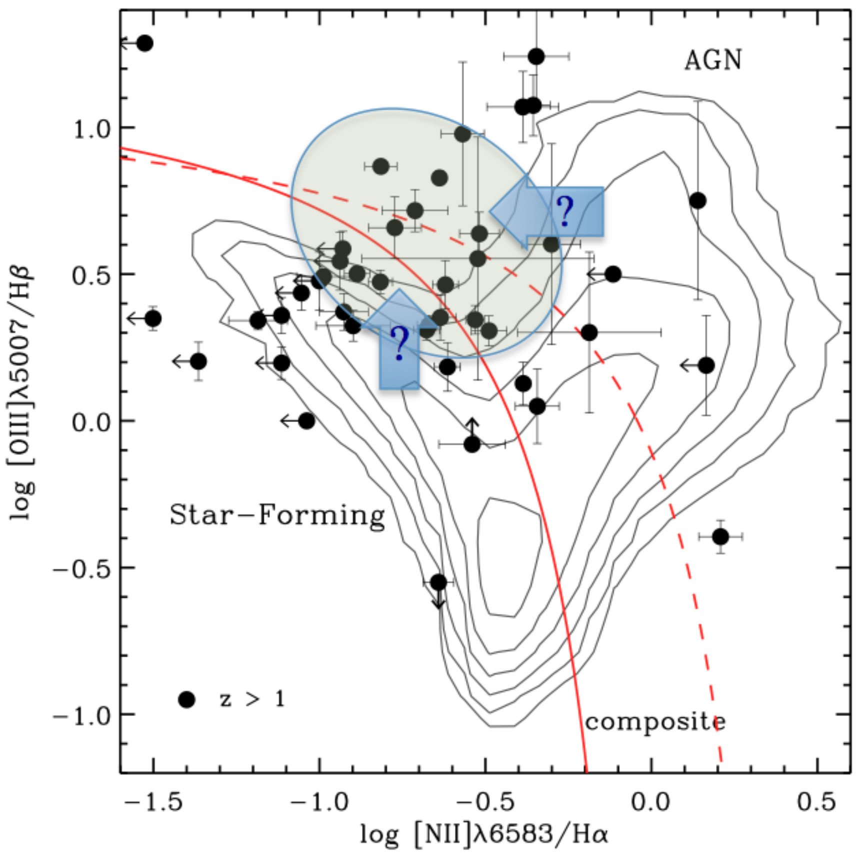
1- Empirical dividing Lines (from >100,000 SDSS galaxies at 0.05<z<0.1)

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



(adapted from Juneau+ 11; tested at z > 1 by Trump+ 13; Newman+ 14; Coil+ 14, and more)

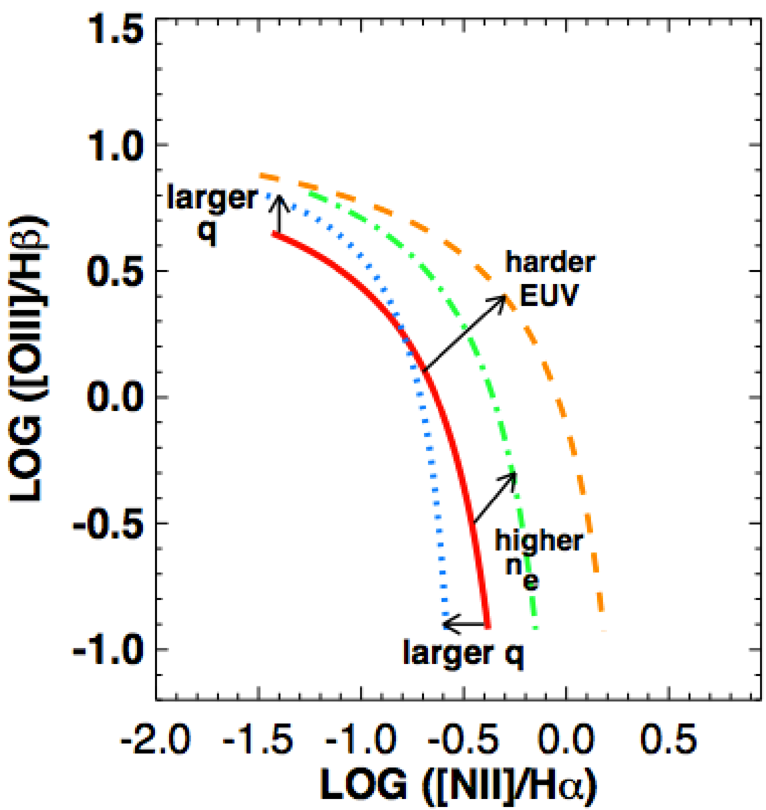
BPT diagnostic at higher redshifts



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, Kewley +13a,b, Shirazi+14, Shapley+14)
  → mode of SF
- Changing AGN contribution? (Groves +06, Wright+10, Trump+11)
  → AGN incidence or duty cycle
- Can we predict/understand this behavior from low-redshift analogs?

BPT diagnostic at higher redshifts - II



Kewley+ 2013a

- Changing HII region conditions?

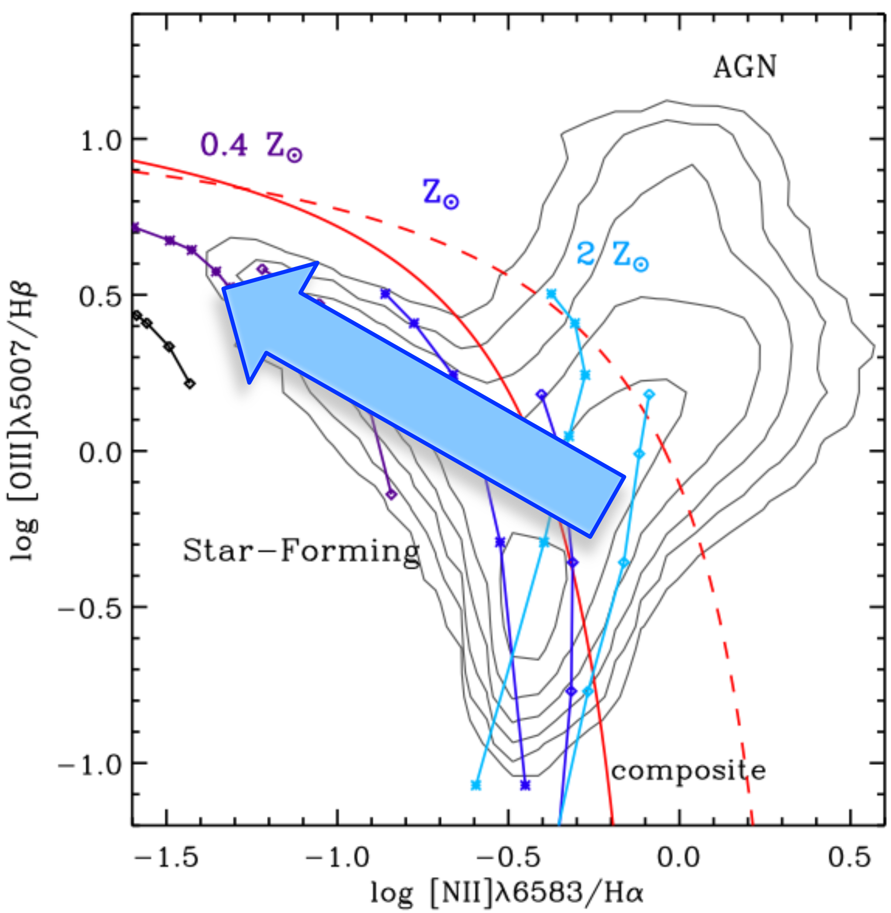
→ Theoretical predictions based on stellar population and photoionization models (e.g., Kewley + 2013a)

→ 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

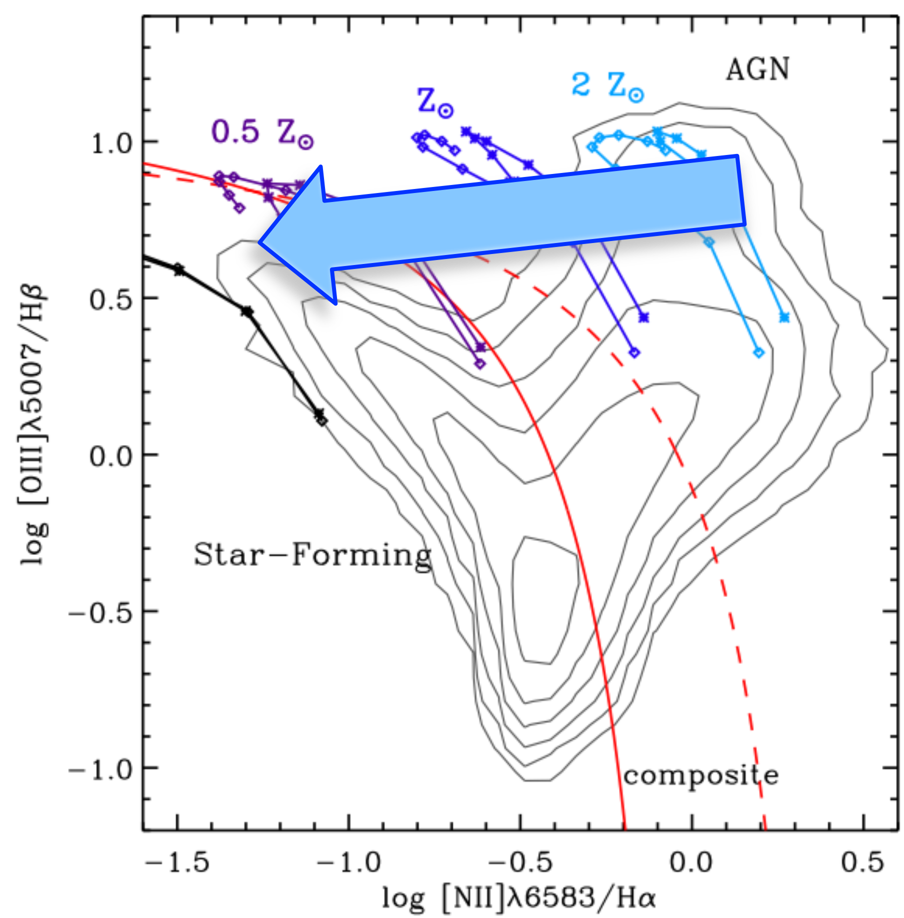
→ Can also help to constrain formation of disk galaxies (inside-out?)

Varying gas-phase metallicity

On Star-Forming Regions

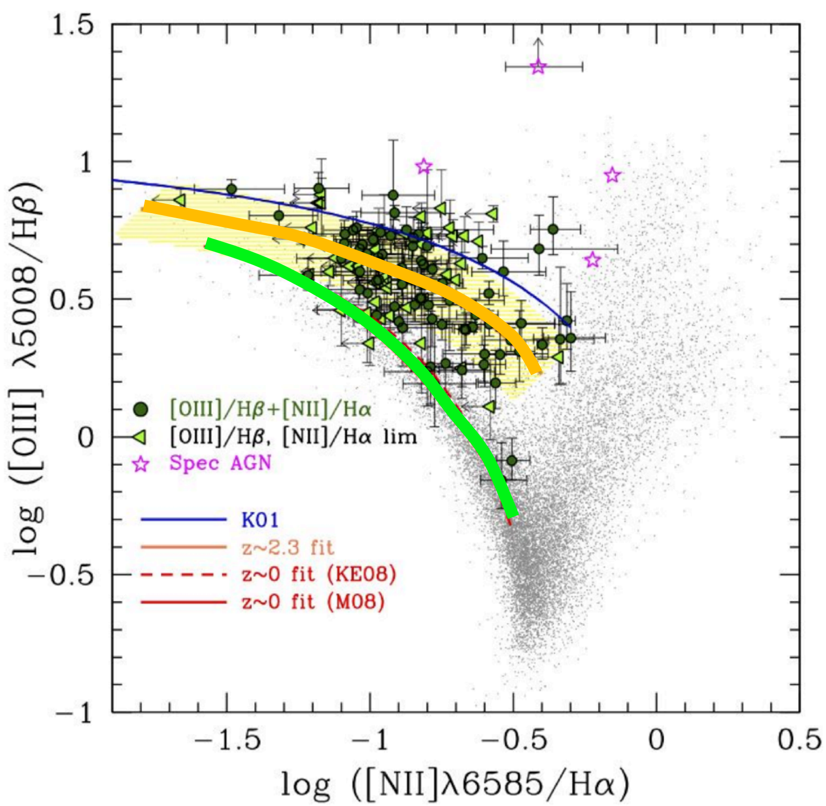


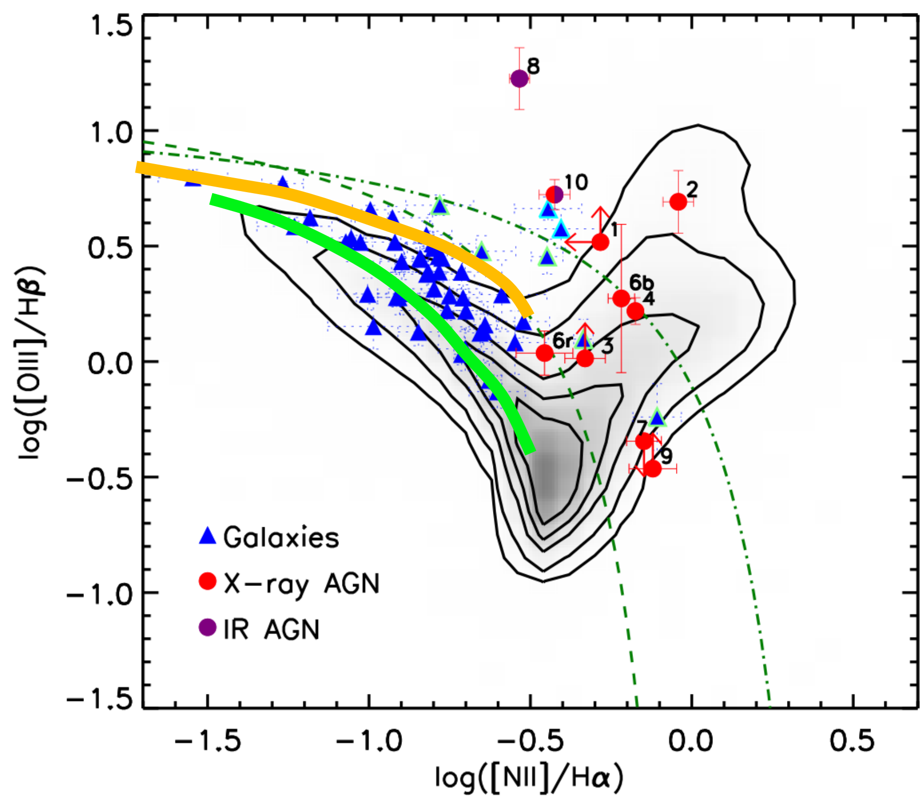
On AGN Narrow-Line Regions



Tracks made with ITERA (IDL Tool for Emission-line Ratio Analysis; B. Groves)

BPT diagnostic at higher redshifts - III



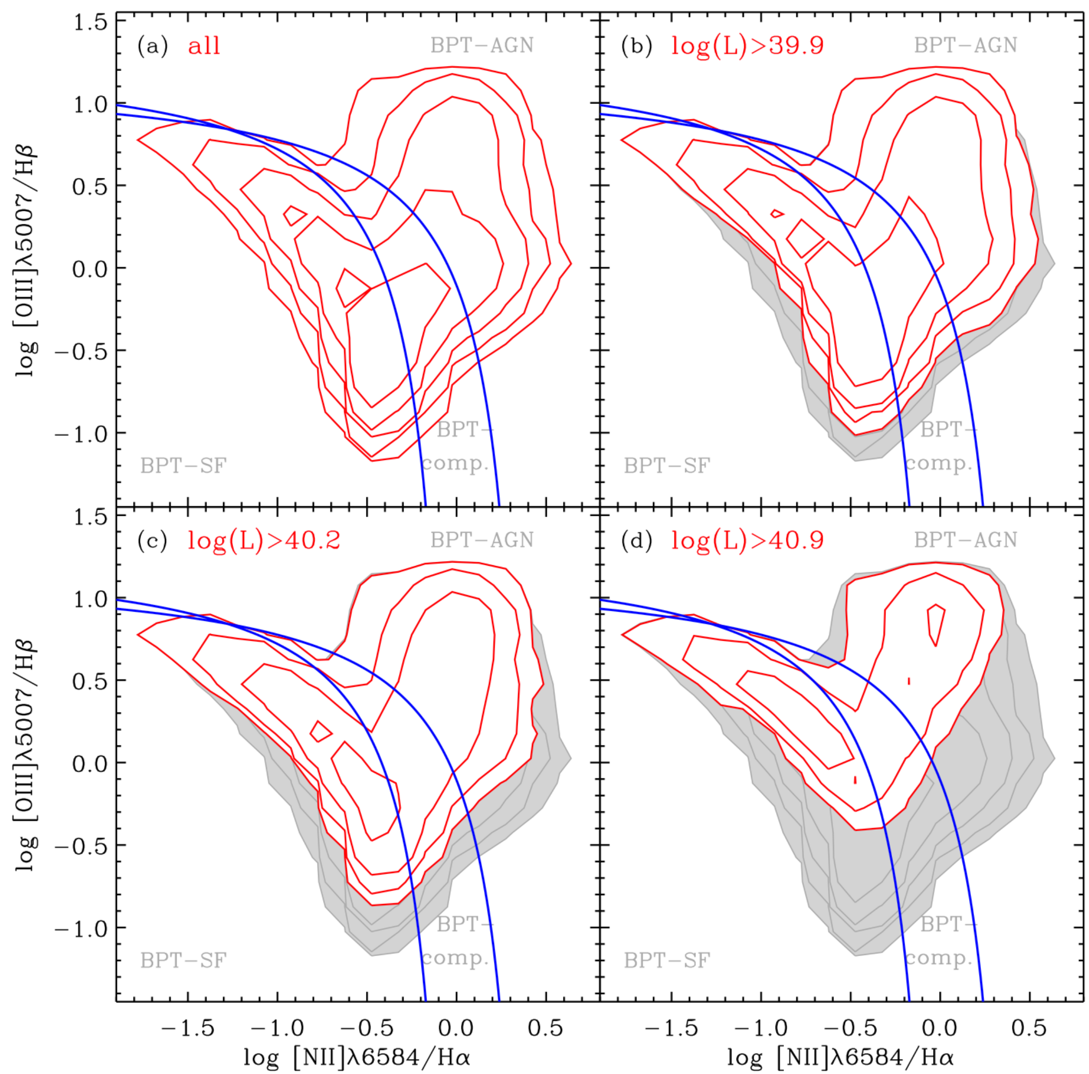


Steidel+ 2014

Coil+ 2014 (also Shapley+ 2014)

Emission-line Luminosity Threshold

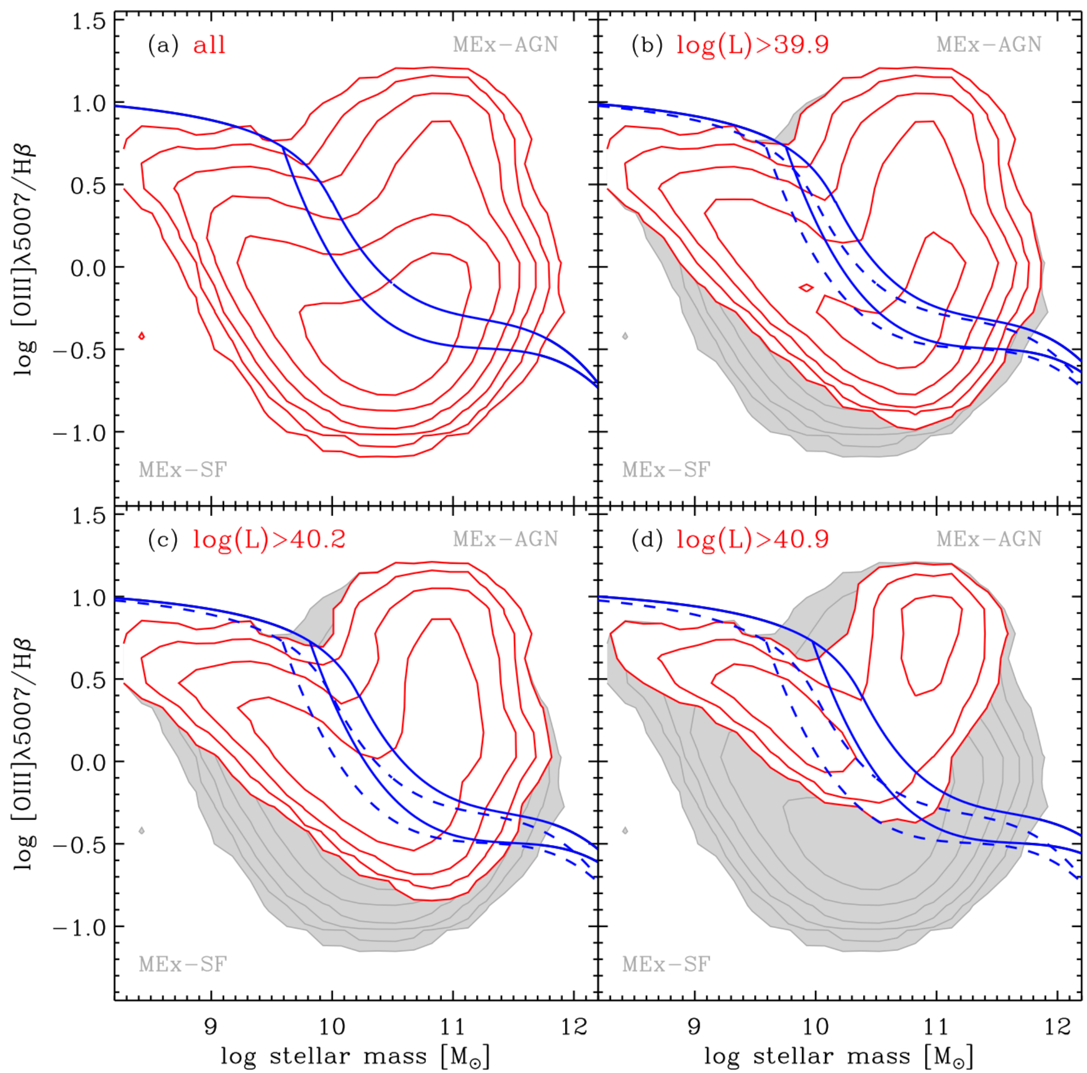
1) BPT



Juneau et al, 2014

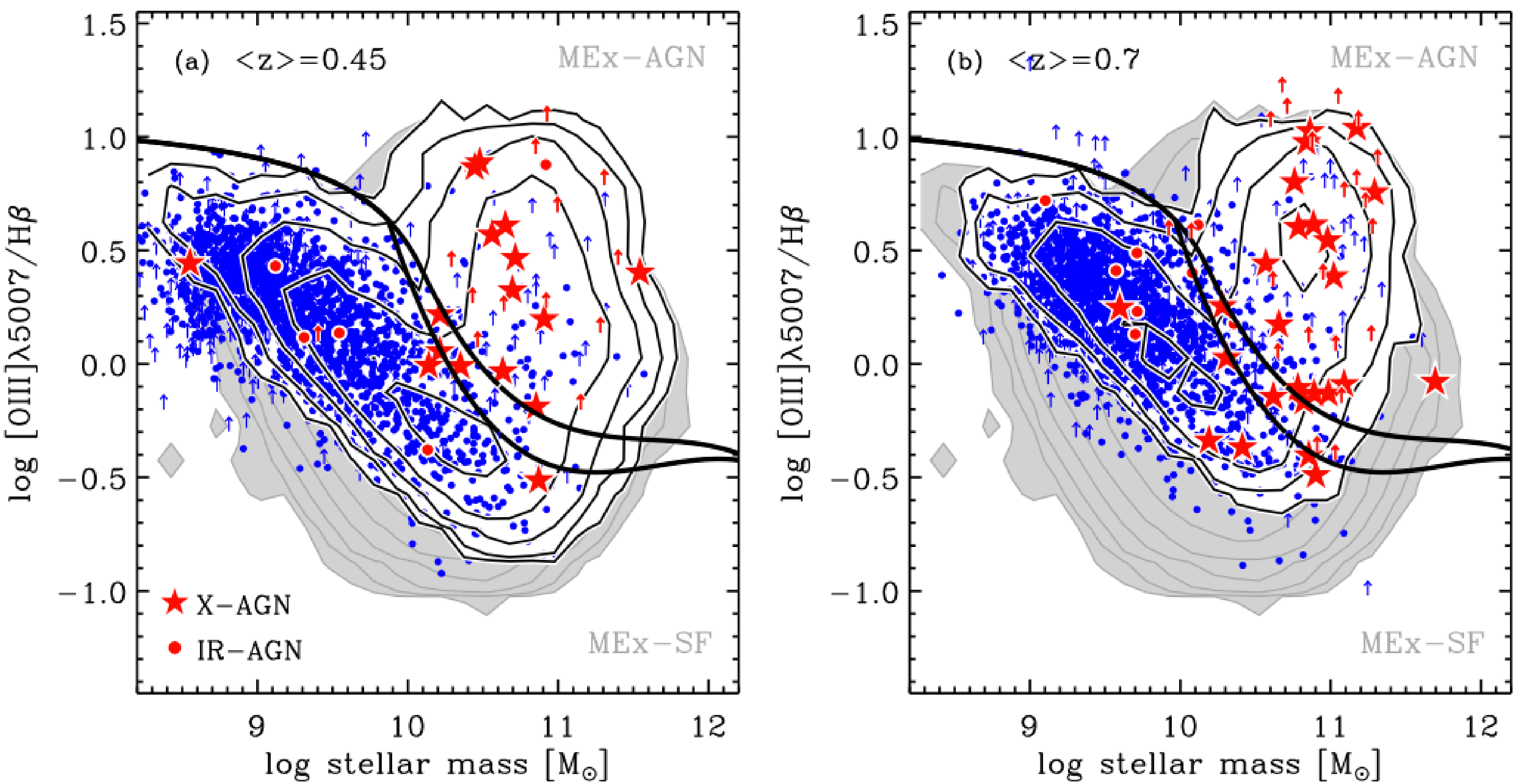
Emission-line Luminosity Threshold

2) MEx



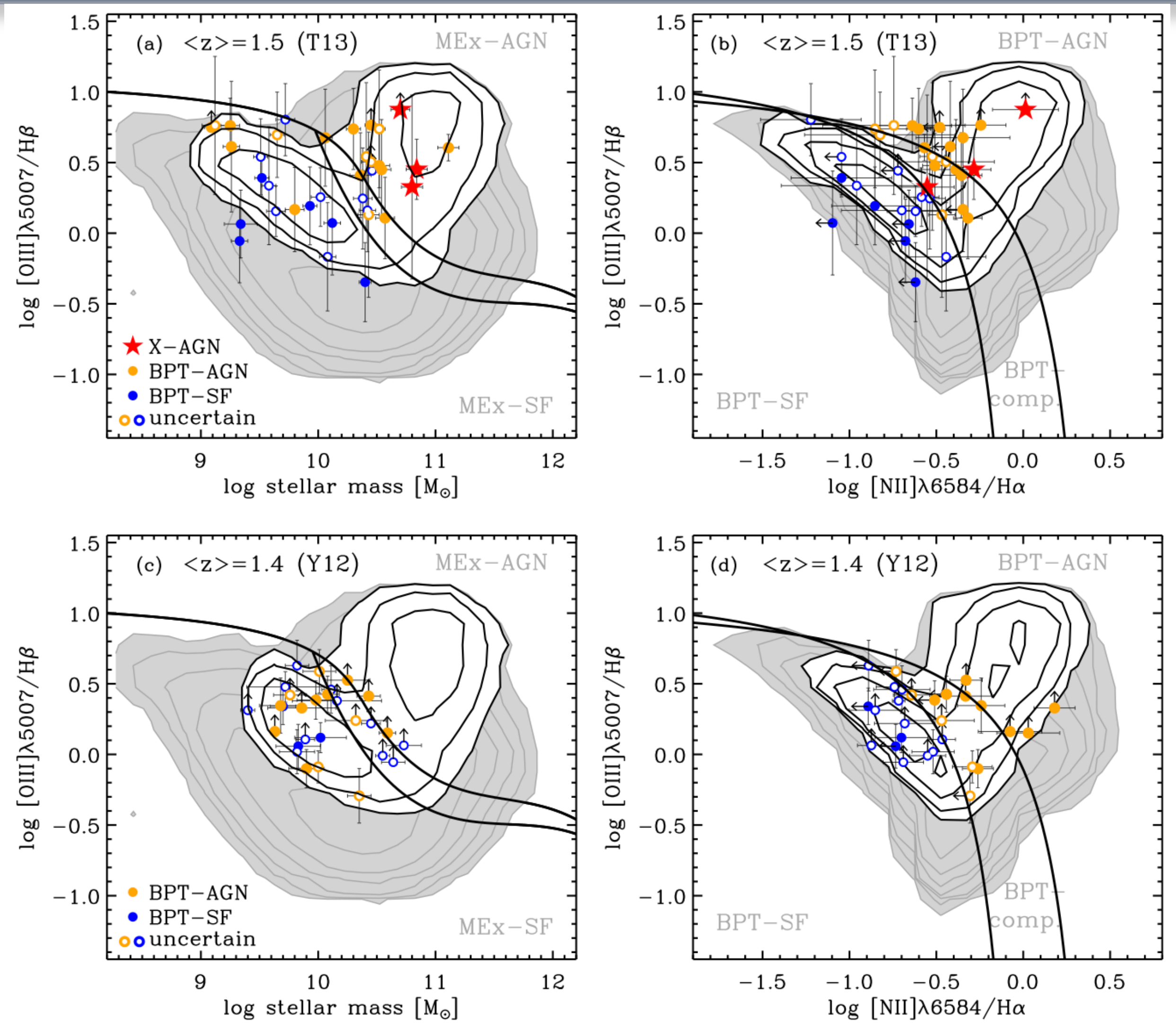
Juneau et al, 2014

Application at 0.3 < z < 1



Juneau et al, 2014

Application at z =1.5

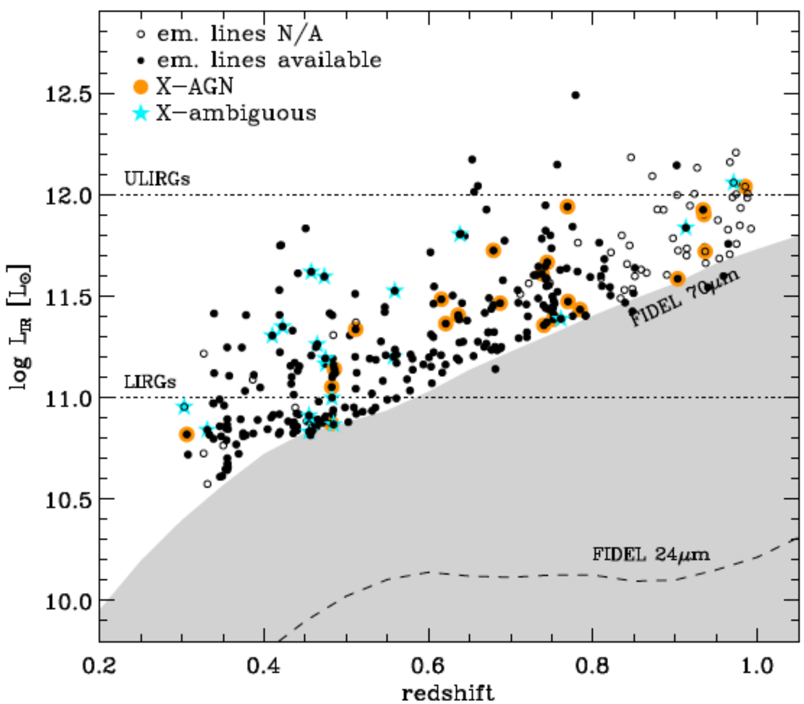


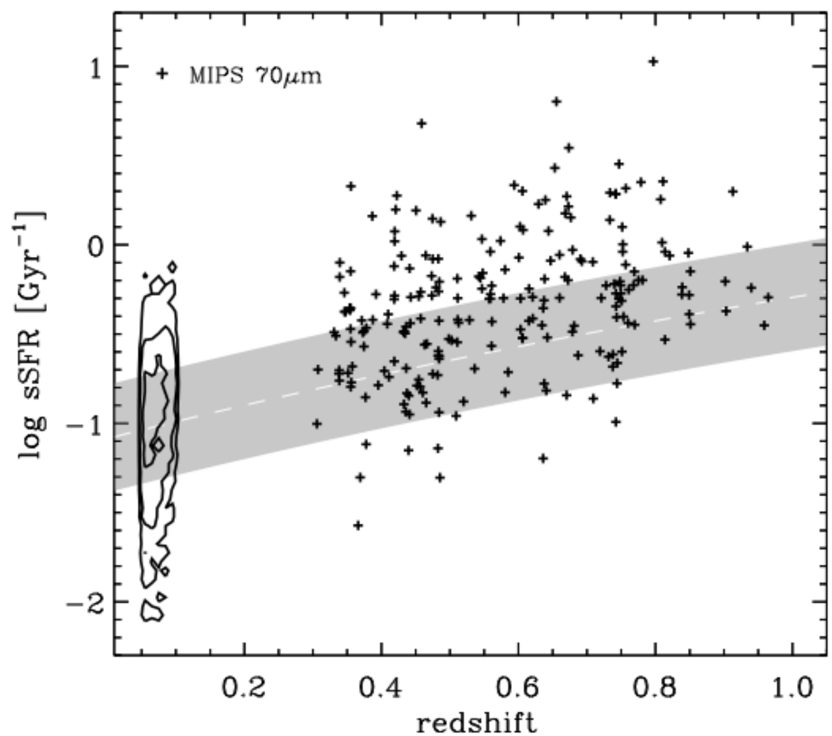
Juneau et al, 2014

AGN in Star-Forming Galaxies

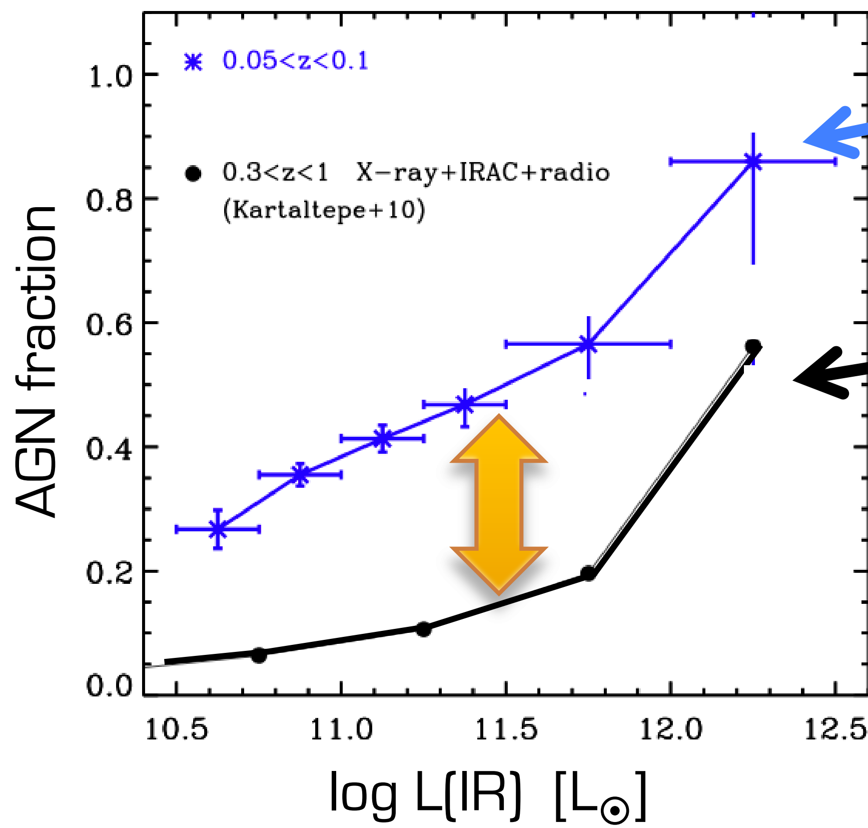
- Selection from the **F**ar-IR **D**eep **E**xtragalactic **L**egacy survey (**FIDEL**, PI: M. Dickinson; catalog in Magnelli+2011)
- 70 μ m-selected sample in GOODS-N and EGS: 2.5mJy (3 σ) with *Spitzer*/ MIPS

→ LIRGs at z=1 (typical star-forming galaxies → major contributors to the cosmic star formation rate; e.g., Le Floc'h+ 2005, Magnelli+ 2009)





Incidence of AGN



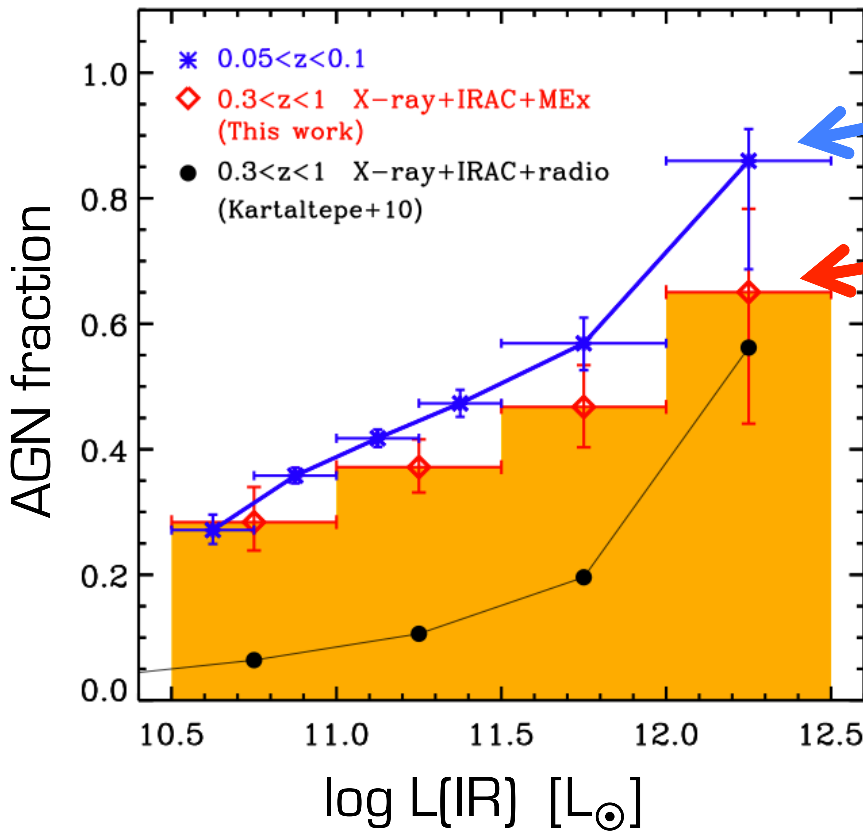
low-z (<0.1) FIR galaxies
(SDSS + IRAS 60 μ m or AKARI 90 μ m)

0.3< z <1 FIR galaxies
(MIPS 70 μ m; also see Symeonidis+10)

X-ray, IR, radio AGN

AGN fraction is *high* in IR galaxies, up to ~100% in ULIRGs (L_{IR}>10^{12} $L_\odot$; e.g., Veilleux+1995, Yuan+2010)

Incidence of AGN



low-z (<0.1) FIR galaxies
(SDSS + IRAS 60 μ m or AKARI 90 μ m)

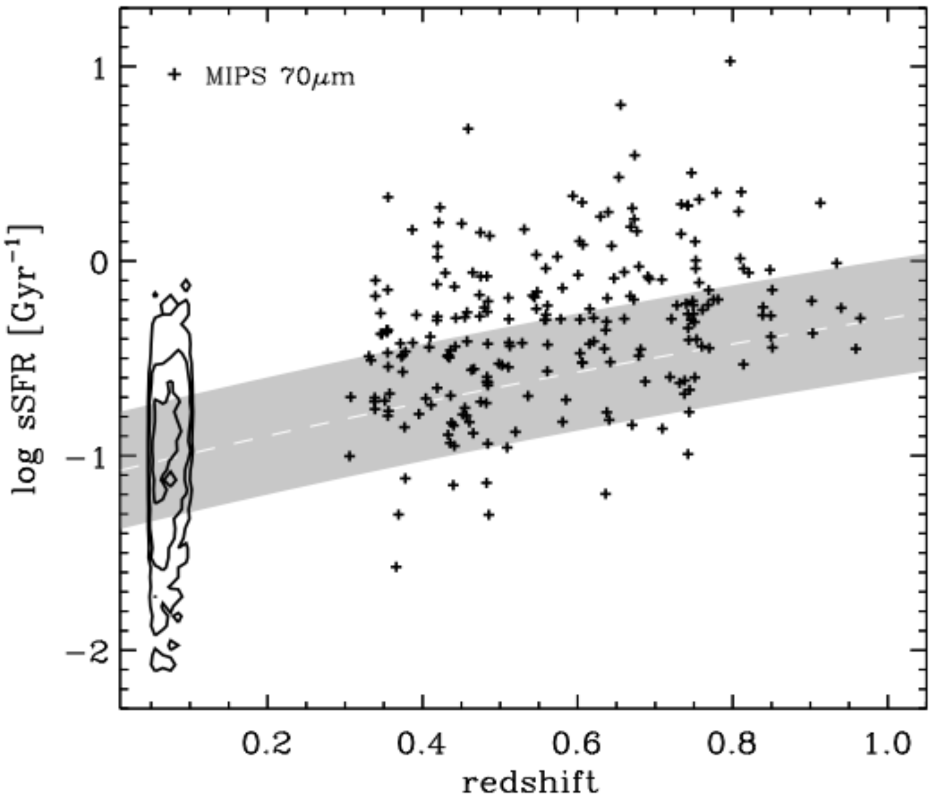
0.3< z <1 FIR galaxies
(MIPS 70 μ m)

→ X-ray, IR, radio & **MEx** AGN

Incidence of AGN vs. L(IR) (~SFR) in intermediate-redshift galaxies is very similar to that in nearby (z~0.07) galaxies

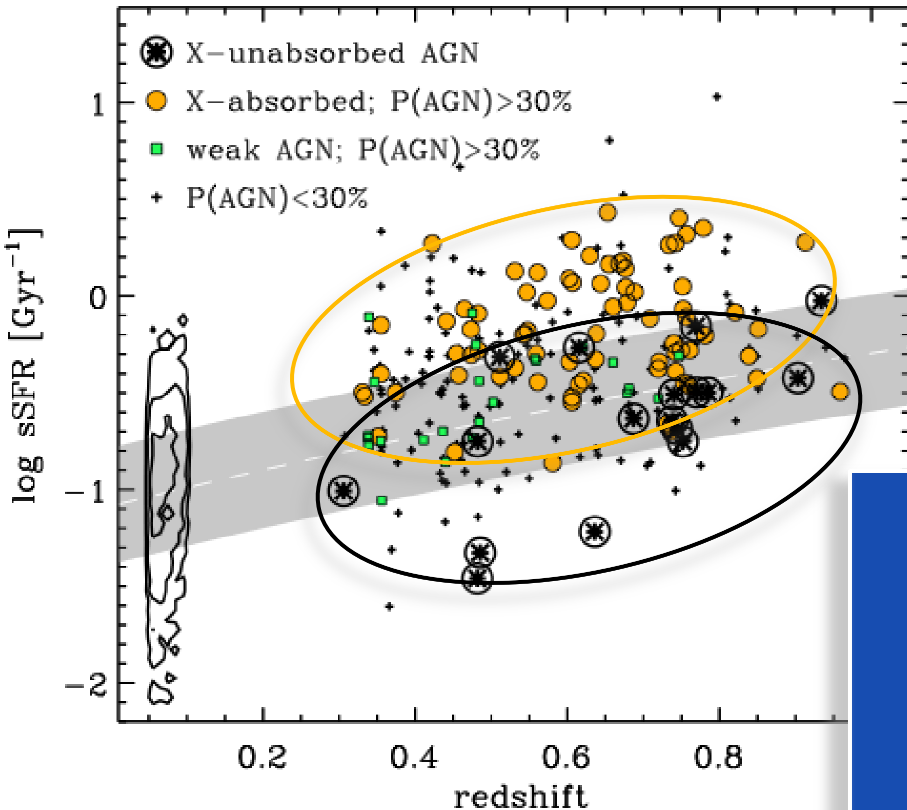
Juneau et al. 2013

AGN obscuration



Spitzer/MIPS 70 selection
(Juneau et al. 2013)

AGN obscuration

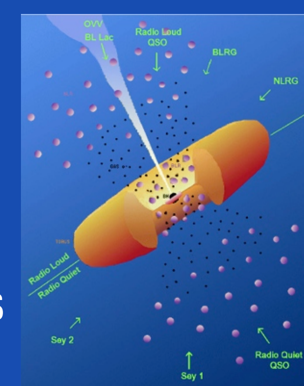


← X-ray Absorbed AGN

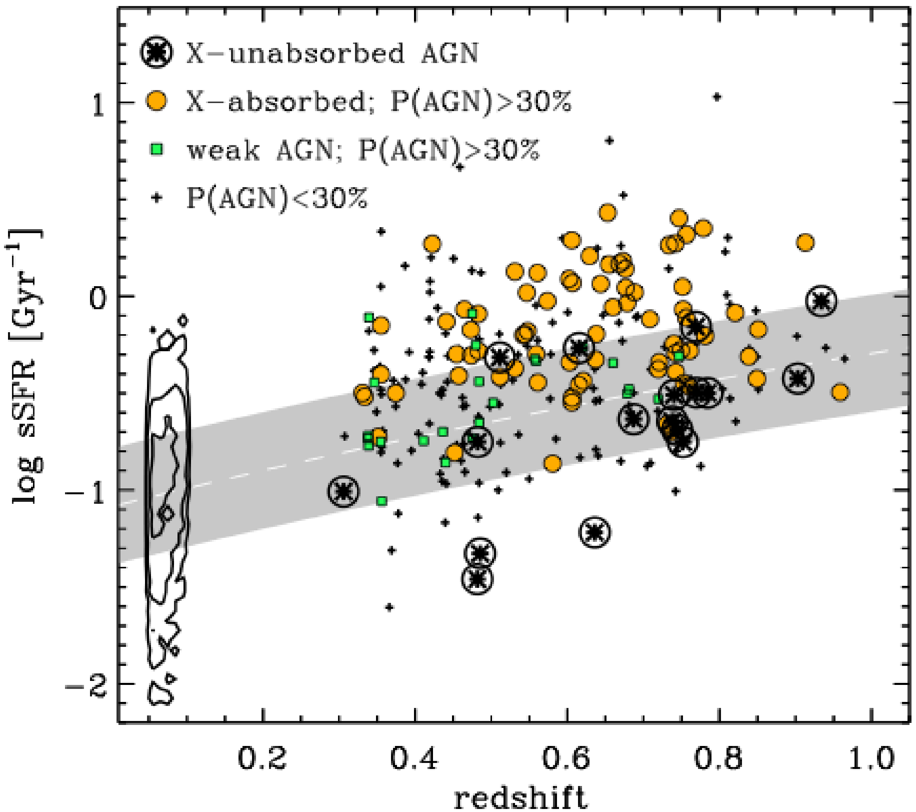
← X-ray AGN (no or moderate absorption)

Spitzer/MIPS 70 selection
(Juneau et al. 2013)

AGN absorption is related to host galaxy (sSFR, tracing gas fraction or geometry)
→ Strong implications for Unified model

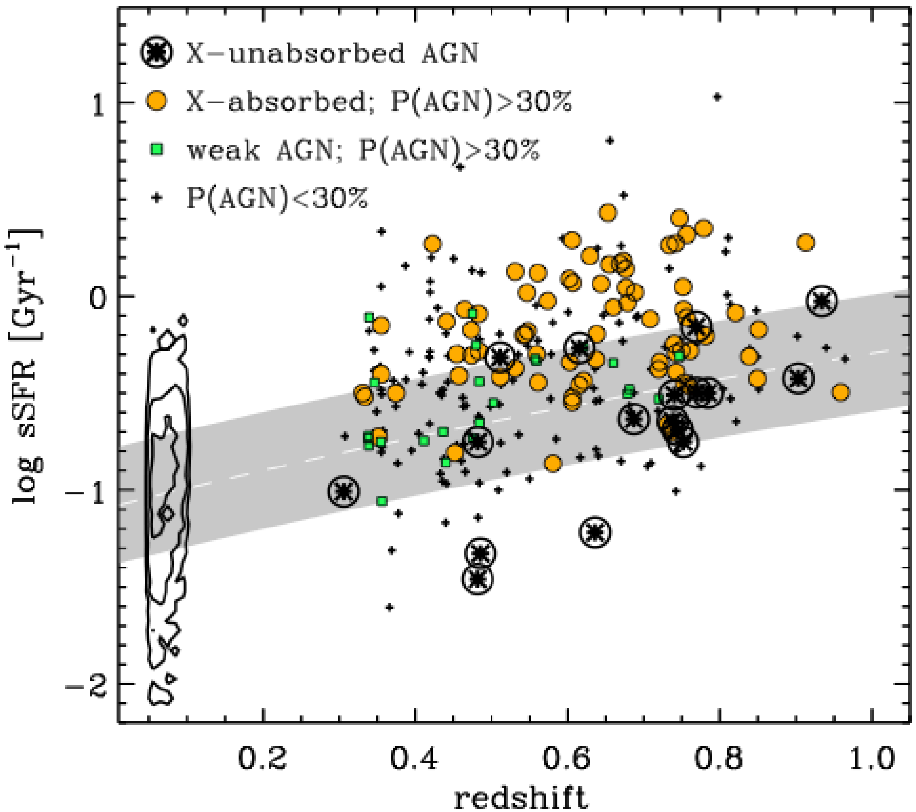


Next... from Spitzer to Herschel

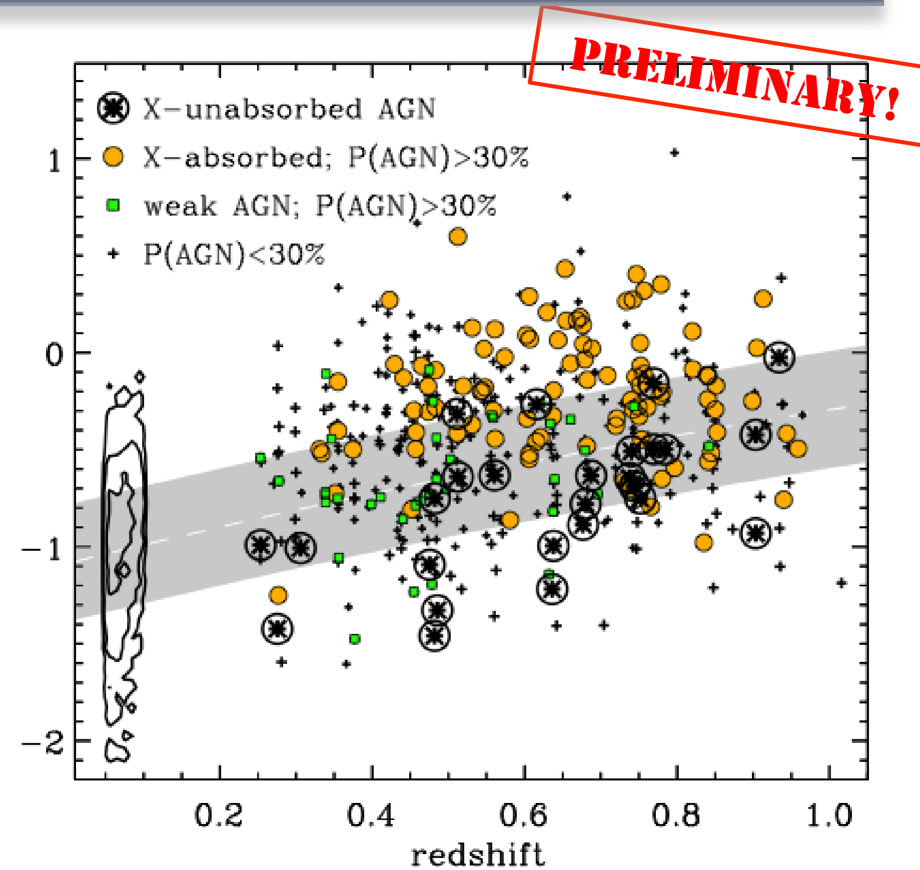


Spitzer/MIPS 70 selection
(Juneau et al. 2013)

Next… from Spitzer to Herschel



Spitzer/MIPS 70 selection
(Juneau et al. 2013)



Herschel/PACS 100 selection
(in prep)

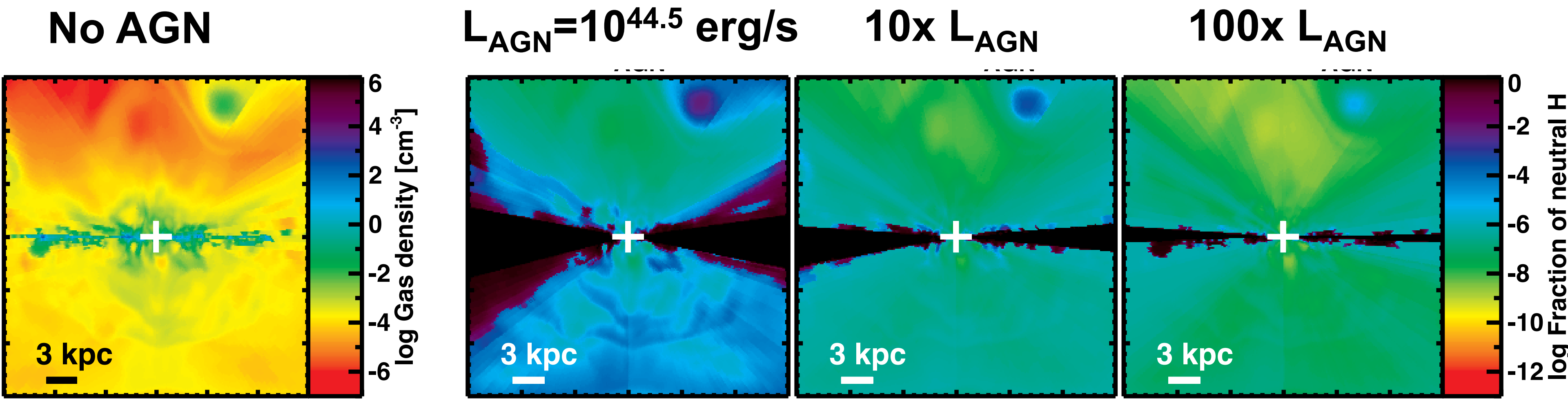
Summary

- Multi-wavelength identification of AGN is crucial for a complete picture
- Need to account for both selection effects and evolution simultaneously!
  - selection effects can exaggerate evolution of "microphysics"
  - Will be important for ALL galaxy spectroscopy surveys: VLT/VIMOS+KMOS, Keck/MOSFIRE, Subaru/FMOS+PFS, etc. + JWST + Euclid + ...
- Increasingly important at higher redshifts because of the evolution of the "macrophysics", i.e., general galaxy population:
  - Higher SFRs and SSFRs
  - Higher incidence of AGN

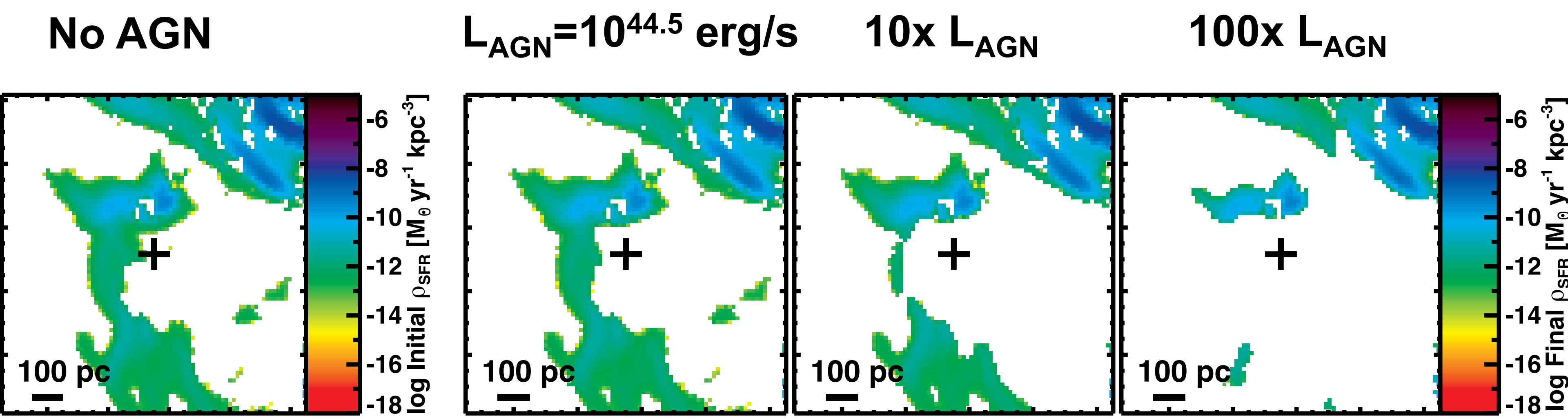
→ More work required to assess feedback by AGN (e.g., Roos, Juneau+14)

Other scientific highlights

- 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)
- AGN obscuration "knows" about host properties (SSFR) → Need to revise the Unification Model
- Concurrence is very common: How about AGN Feedback?
  - AGN-driven outflows do not disrupt disks (Gabor+13,14)
  - Effect of AGN photoionization on SF (Roos+14: **arXiv 1405.7971**)
  - Also potential role of radio jets (e.g. Dubois+13)



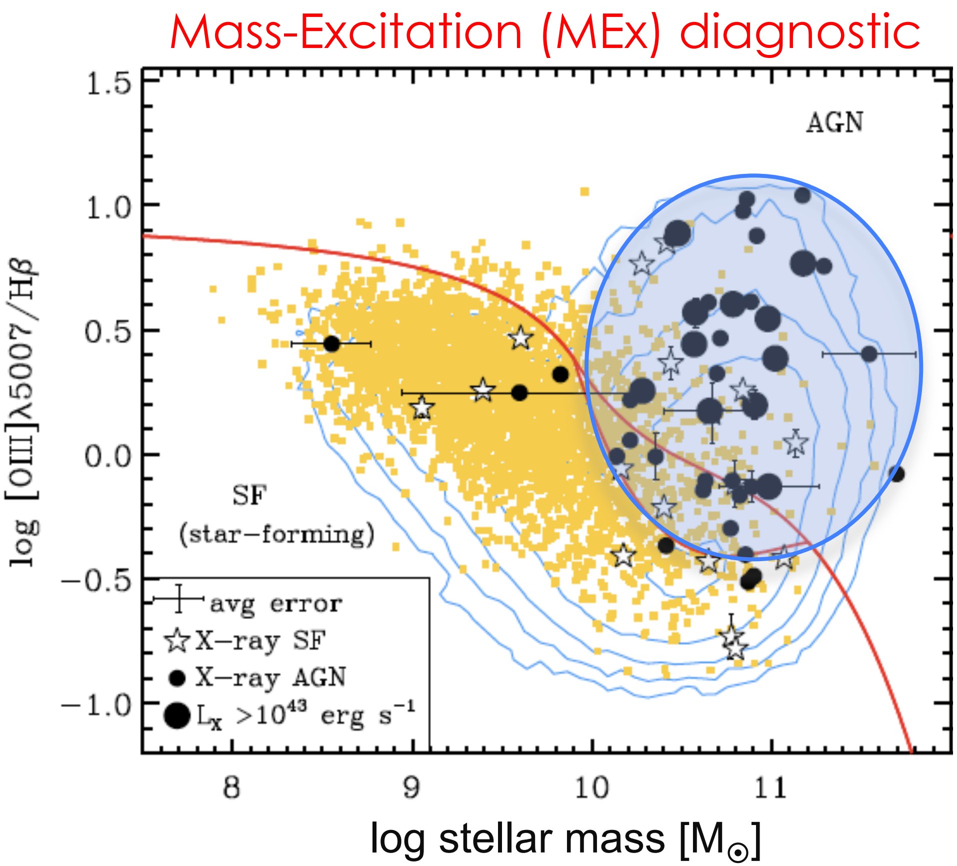
AGN photoionization added in post-processing with Cloudy (Ferland 2013) in high-res sims:
– Large-scale: obvious ionization cones, broaden with L(AGN); negligible effect on SFR
– Zoom in: illustrates only more diffuse gas is affected → clumps shield themselves



Roos+14: **arXiv 1405.7971**

Thank You

MEx confirmed with X-rays

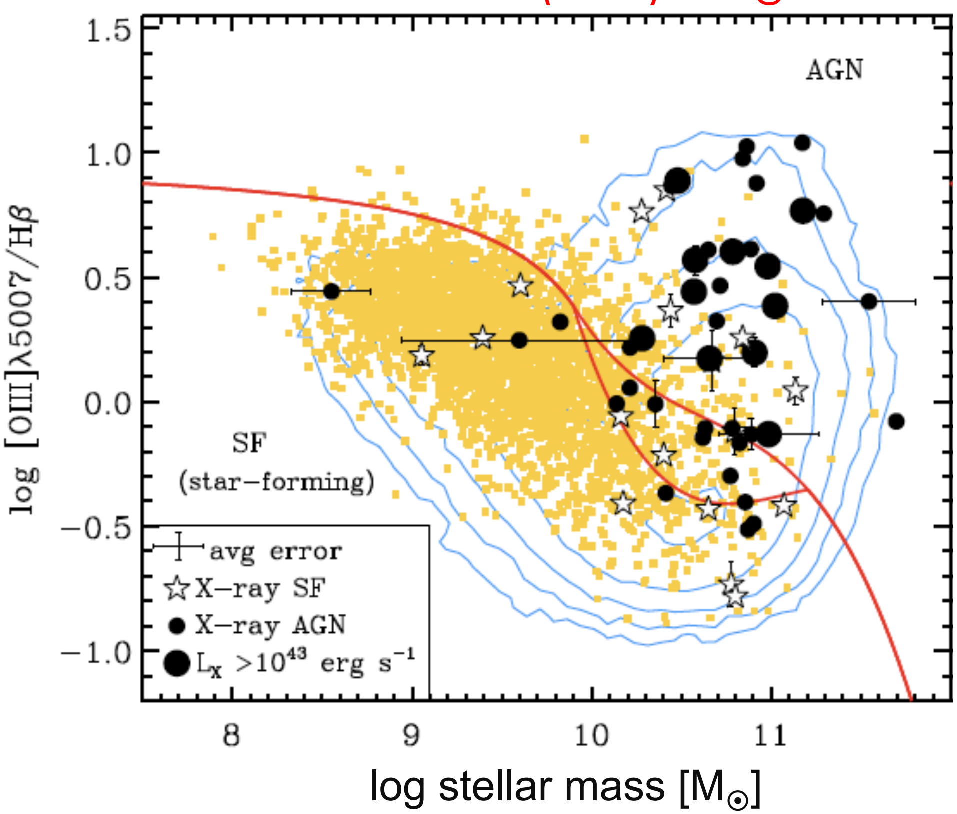


- MEx diagram identifies 85% of X-AGN that have emission lines

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)

MEx confirmed with X-rays

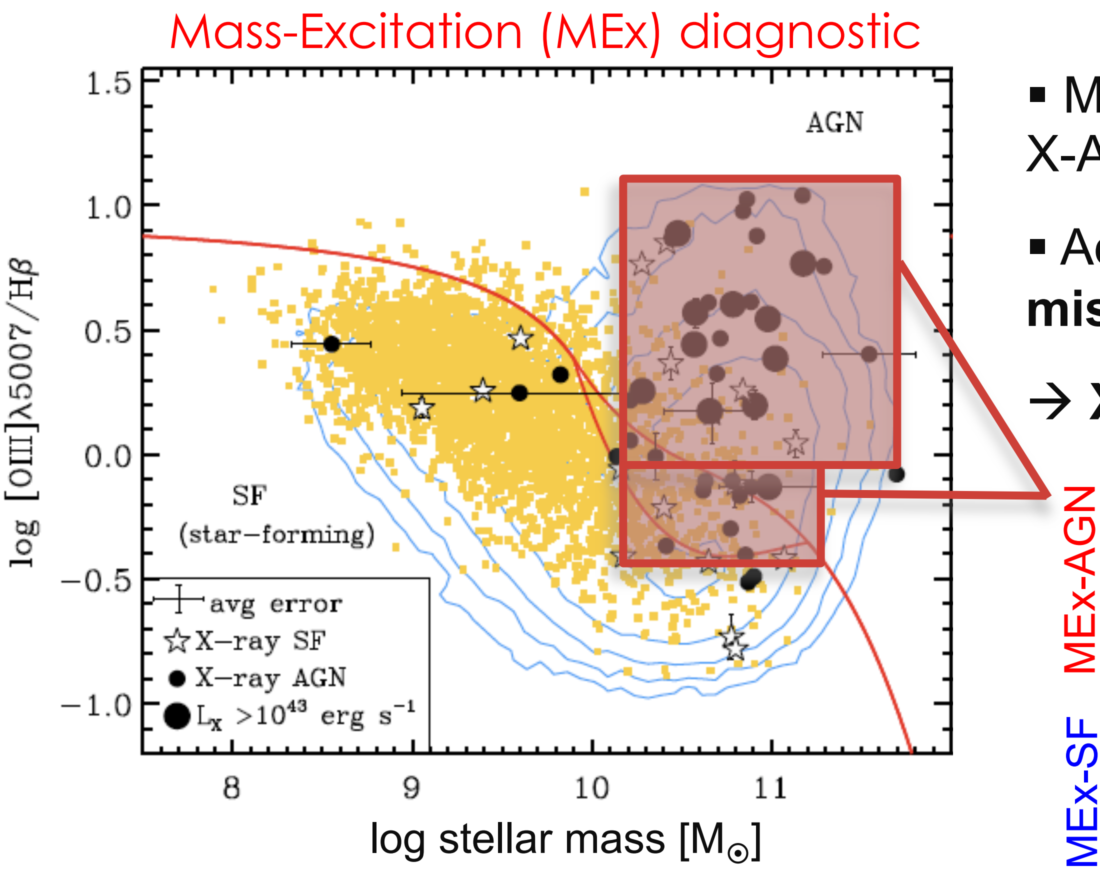
Mass-Excitation (MEx) diagnostic



- MEx diagram identifies 85% of X-AGN that have emission lines
- Additional AGN **missed or misclassified in the X-rays**

__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)

MEx confirmed with X-rays



- MEx diagram identifies 85% of X-AGN that have emission lines
- Additional AGN **missed or misclassified in the X-rays**

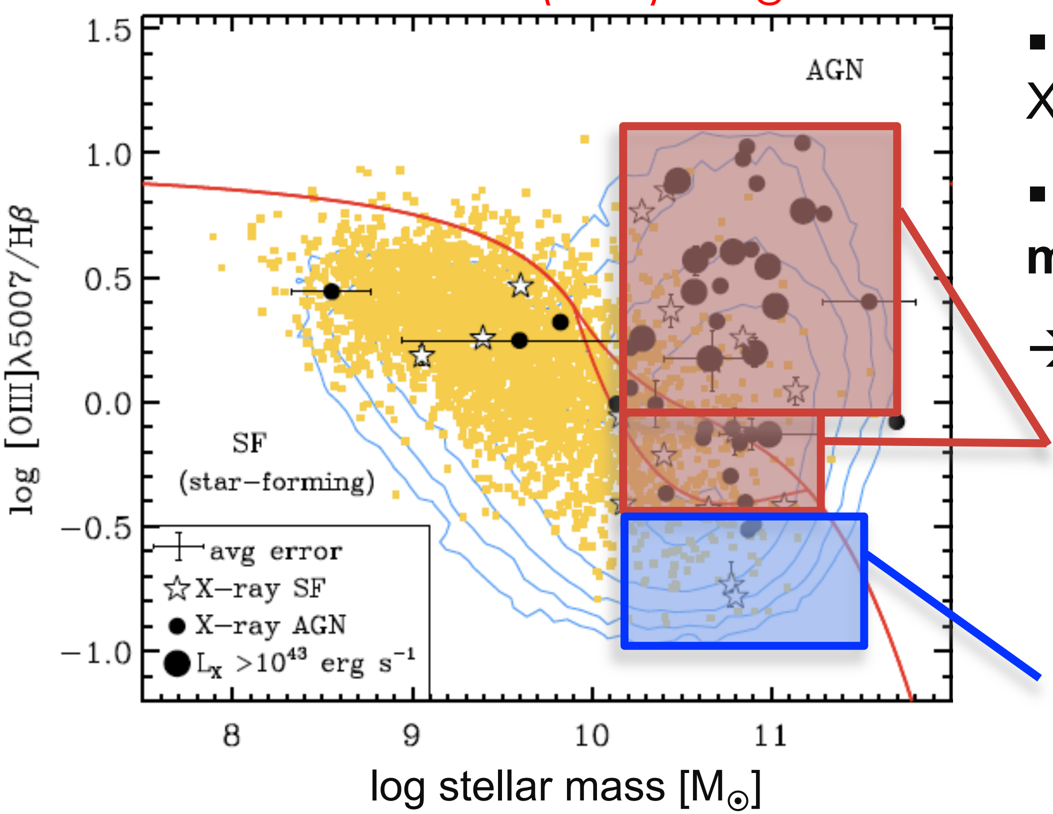
→ **X-ray stacking**

- *Chandra*'s soft & hard bands yield a flat X-ray spectral index (Γ~0.6): **some obscured AGN!**
- Only soft band detection: **consistent with SF**

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)

MEx confirmed with X-rays

Mass-Excitation (MEx) diagnostic



- MEx diagram identifies 85% of X-AGN that have emission lines
- Additional AGN **missed or misclassified in the X-rays**

→ **X-ray stacking**

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

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

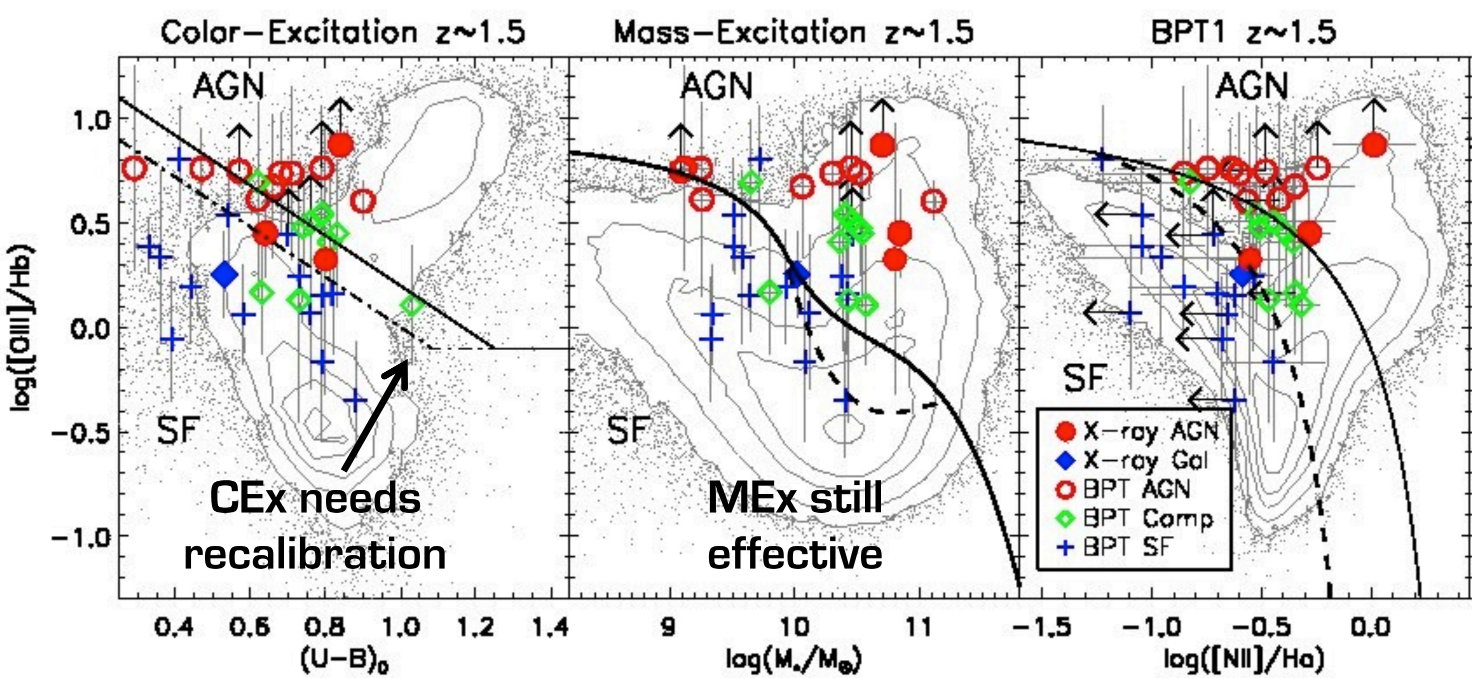
Sample: 3,386 galaxies at **0.3<z<1** with [OIII]λ5007, Hβ & stellar mass in **GOODS-North** & **EGS**
Chandra X-ray: 2 Msec in GOODS-N (Alexander+ 03); 200 ksec in EGS (Nandra+05, Laird+09)

AGN diagnostics at z=1.5

Sample: emission-line galaxies at z=1.5

→ low-mass galaxies without strong bulges (some clumpy)

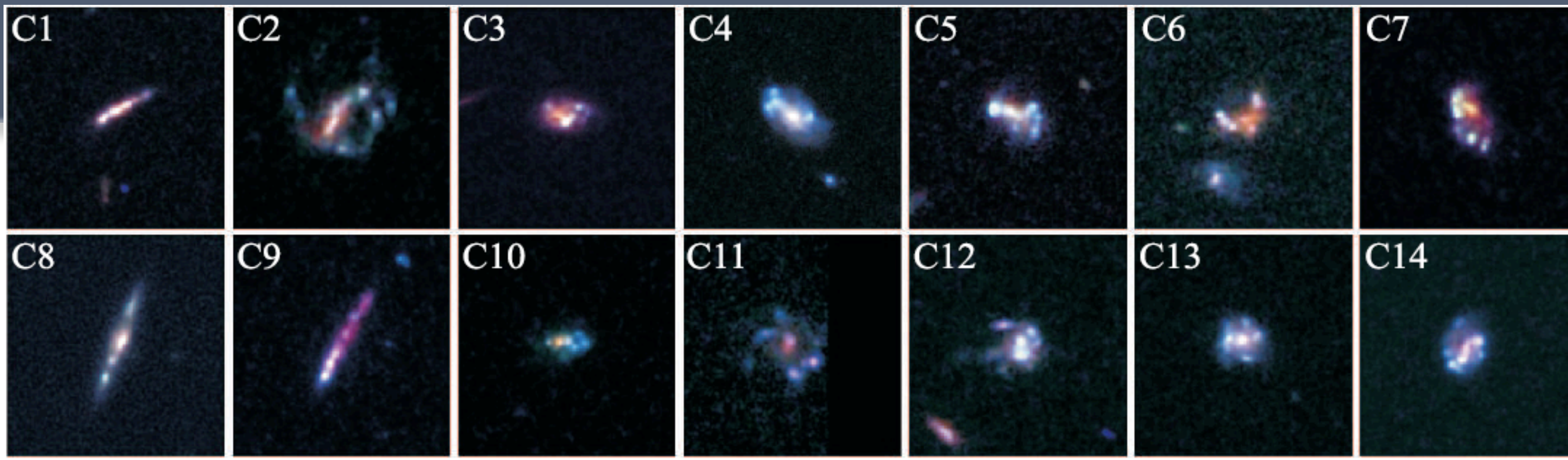
AGN: X-ray (Chandra 4Ms) & BPT (WFC3 + MOSFIRE)



~50% host X-ray/BPT AGNs!

Trump et al (2013)

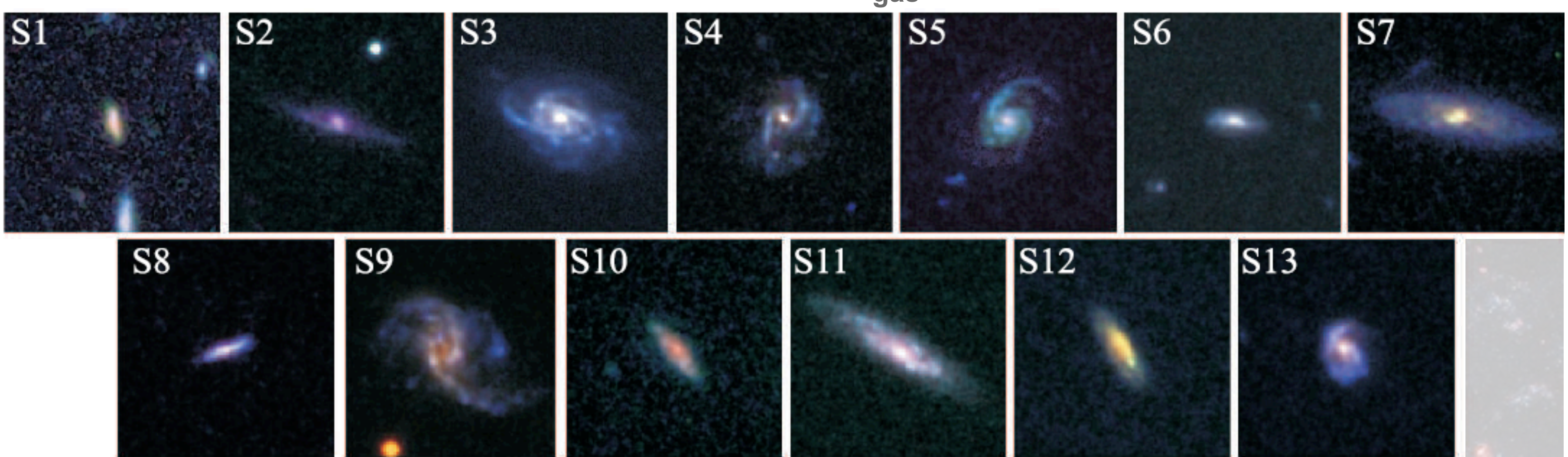
Clumpy vs. Stable disks



Very clumpy - violently unstable - high sSFR and f_{gas}

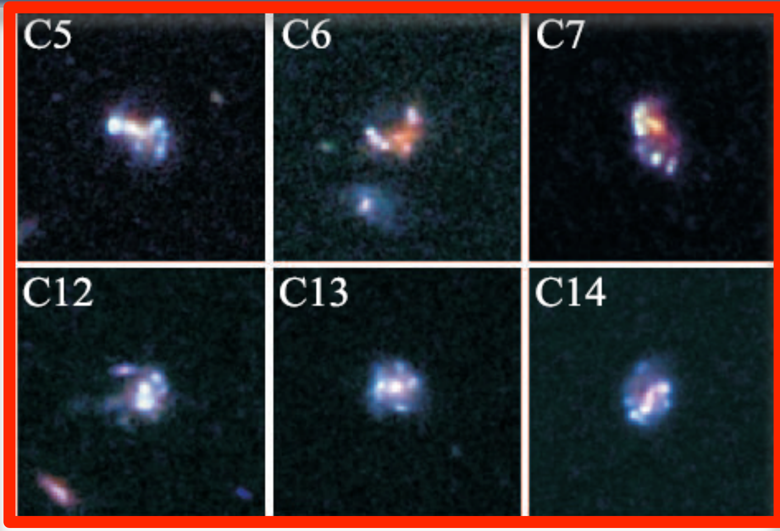
In GOODS-South, redshift and mass-matched, M~ few 10^{10}*

More Stable - arm/bar-dominated, low sSFR and f_{gas}

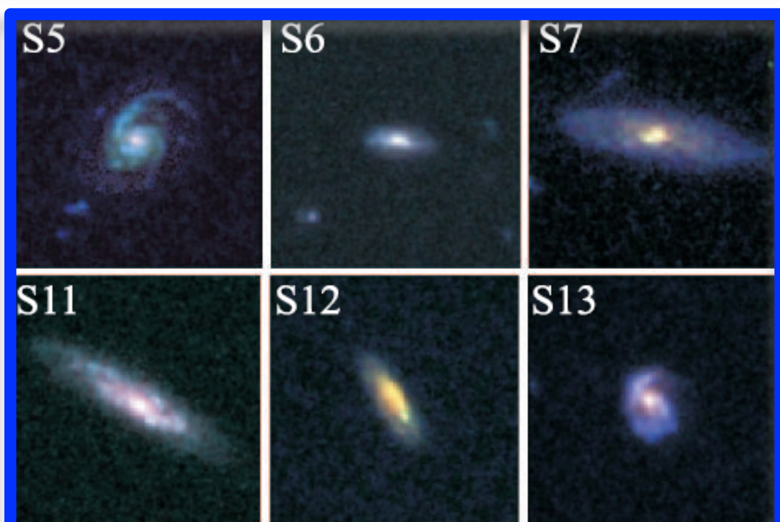


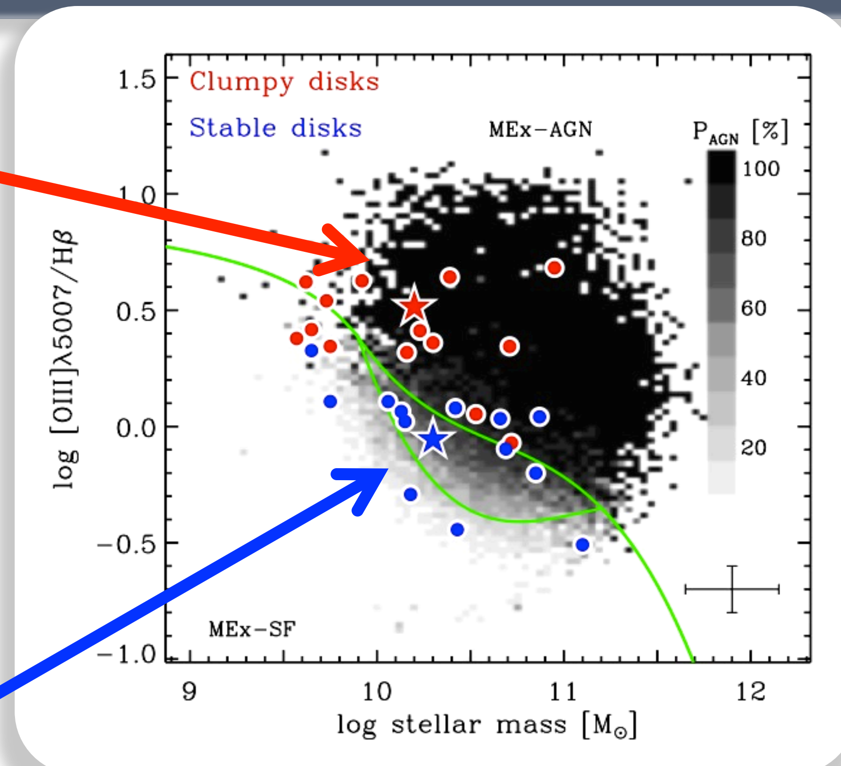
Clumpy disks fuel BH growth

Clumpy (unstable) disks



Stable disks





- New mode of BH growth in violently unstable disks (Bournaud+11; Bournaud, Juneau+ 2012)
- Confirmed with X-ray stacking