Cosmic Evolution of Interstellar Gas and Black Holes in Galaxies

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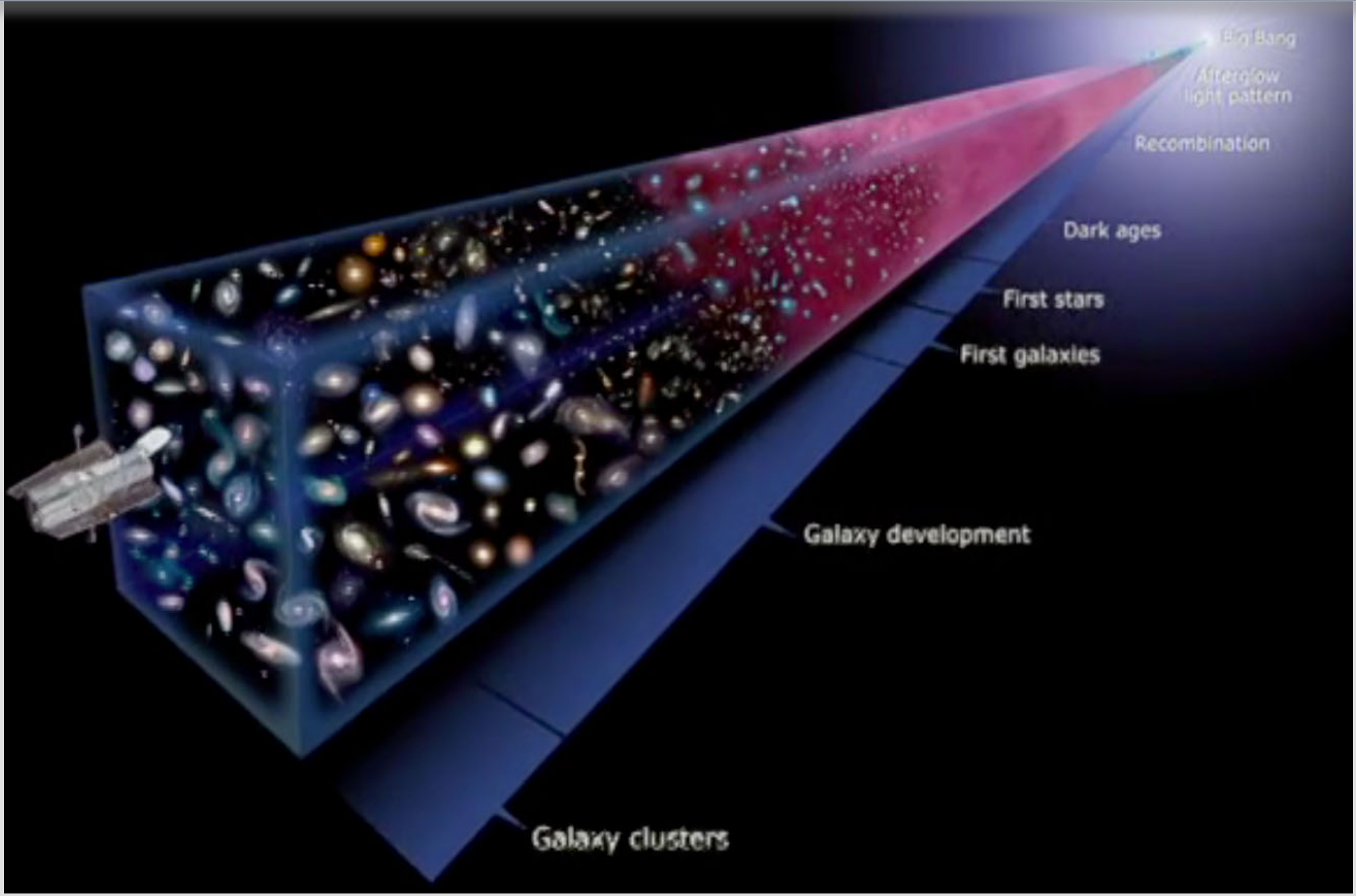
DE LA RECHERCHE À L'INDUSTRIE
cea

Centaurus A
(image credit: ESO)

Outline

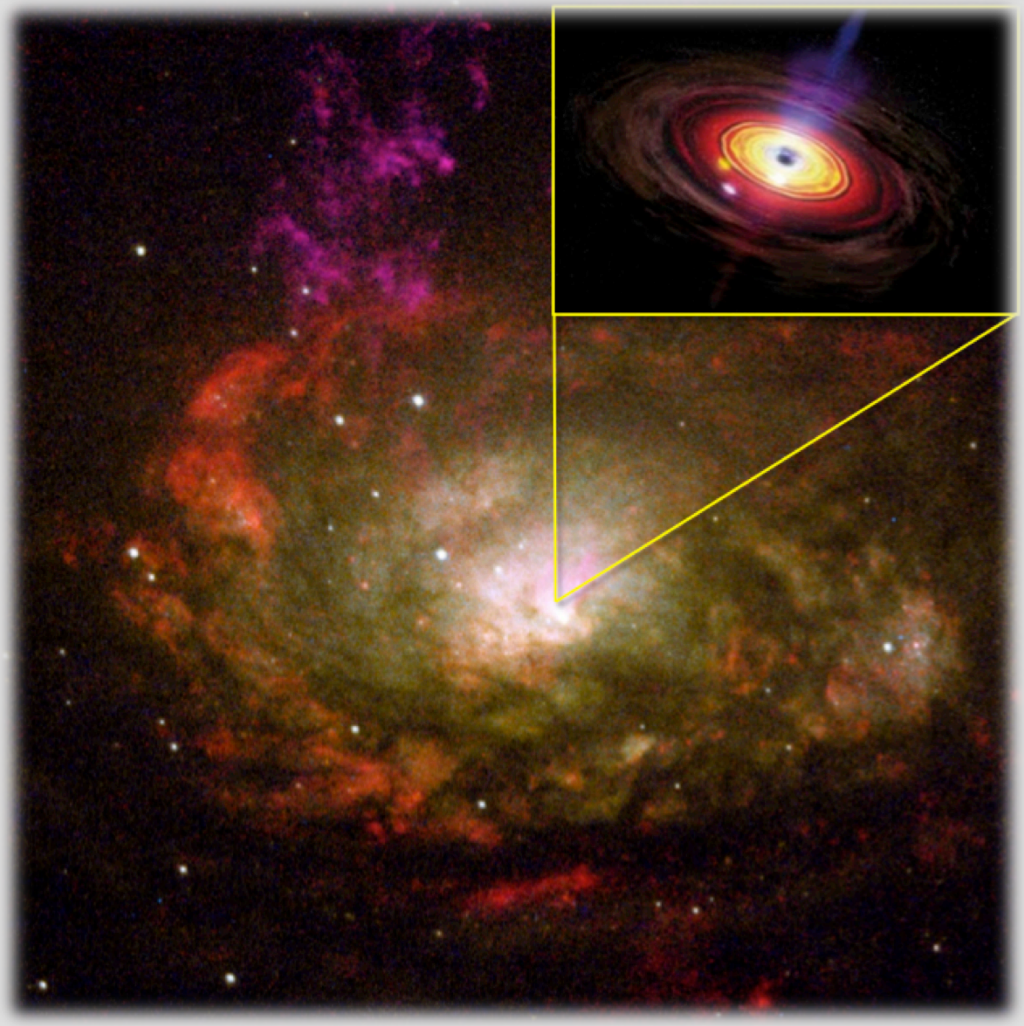
- Intro: Active Galactic Nuclei & Star Formation in galaxies
- Digging into the physics:
  - Galaxy evolution processes
  - Interstellar gas – BPT & MEx diagnostic diagrams
- Challenges at high redshifts for AGN/SF diagnostics
- AGN incidence (& obscuration) in star-forming galaxies

Evolution of Galaxies



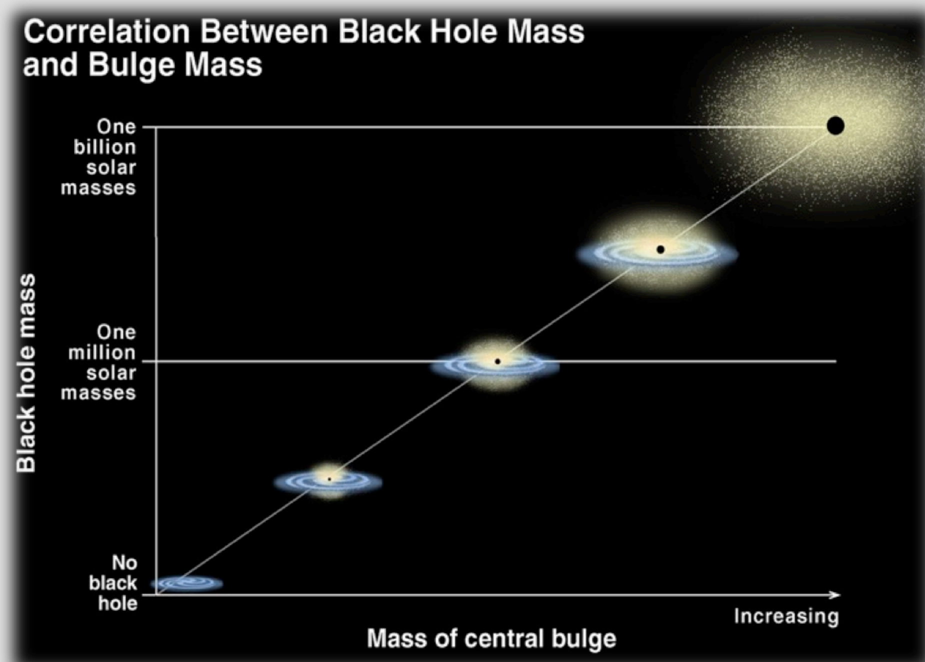
BH-Galaxy Connection

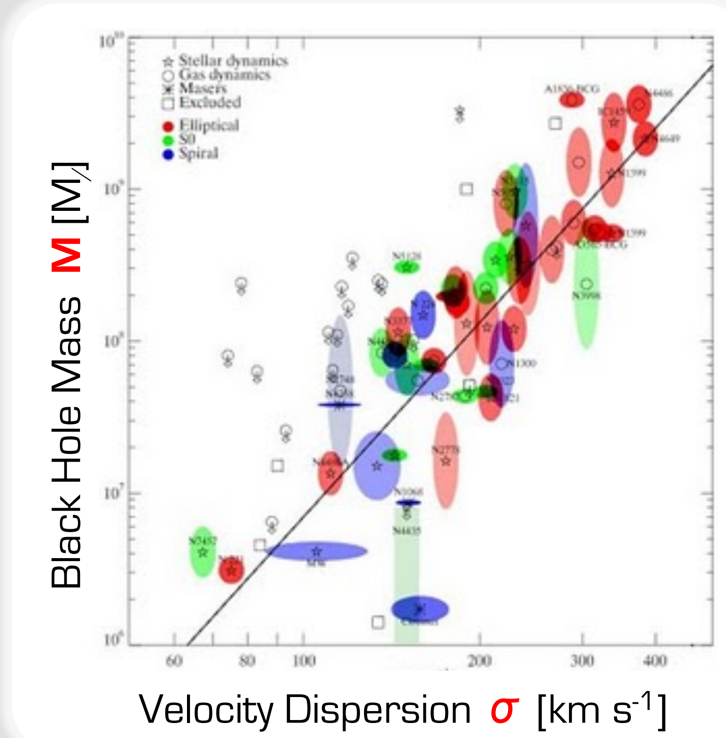
- M-σ relation (e.g., Magorrian+ 1998; Ferrarese & Merritt 2000; Haring & Rix 2004)
- Similar cosmic growth history: peak at z≈2, decline at later times (e.g. Barger+01, Merloni+04,06, Hopkins+04; Bouwens+10)
- Need for negative AGN feedback in cosmological simulations (e.g., Croton+06, Bower+06)



M-sigma relation

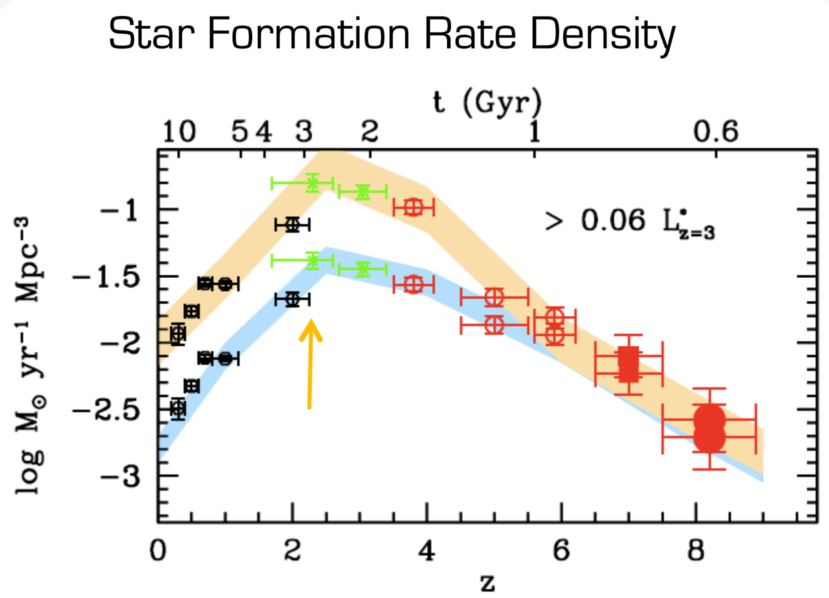
- Black-Hole Mass – Galaxy Velocity Dispersion (M-σ) relation
  (e.g., Magorrian+ 1998; Ferrarese & Merritt 2000; Haring & Rix 2004, but see also Janhke+2011, Kormendy & Ho 2013)

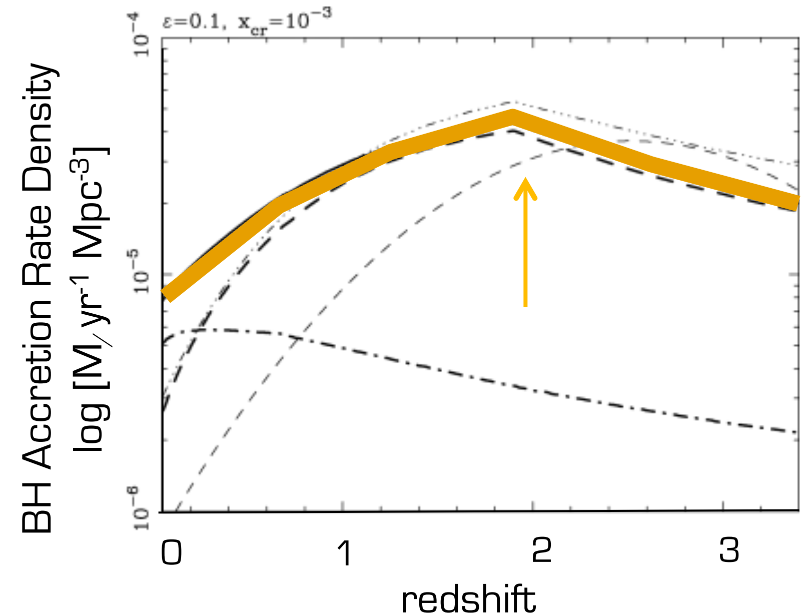




Gultekin et al. 2009

Growth rate histories





Bouwens et al. 2010 (also see Hopkins+04)

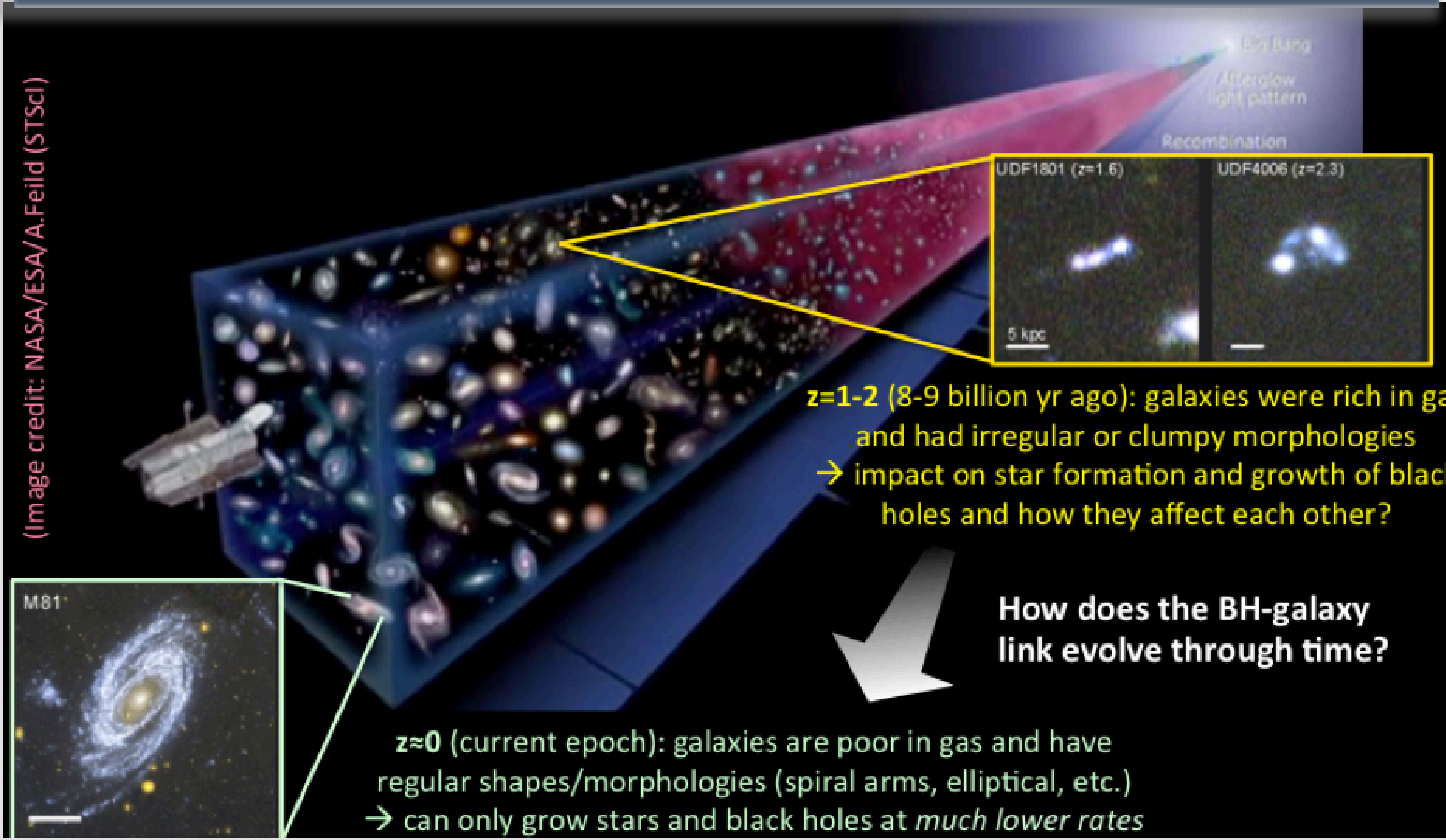
Merloni et al. 2004 (also see Barger et al. 2001)

- Star formation history and black hole accretion history peaked at z~2 and declined steeply since z=1
- Star formation rate / black hole accretion rate ~ constant *when taking volume-averages* (z=1-2, Mullaney+ 2012; also seen as sBAR tracking sSFR by Bongiorno+ 2012)

Some galaxy evolution drivers

- Major mergers: declining rate with time (e.g., Lotz+2008,2011; Kartaltepe+2012)
- Large-scale secular instabilities: bars (and spiral arms) (sharp decline of bar fraction since z=1; Kraljic+2013)
- Large-scale violent disk instabilities: giant clumps (Elmegreen +2007, Bournaud+2008)
- Influence of environment (dark matter haloes, clustering: galaxy clusters vs. groups vs. filaments vs. voids) (e.g. Peng +2010,2012; Gabor+2013)
- Higher gas fractions in “normal” galaxies at higher redshift (Daddi+2010, Tacconi+2012)
- Cold flow paradigm? (e.g., Dekel+2009)

Evolution of Galaxies

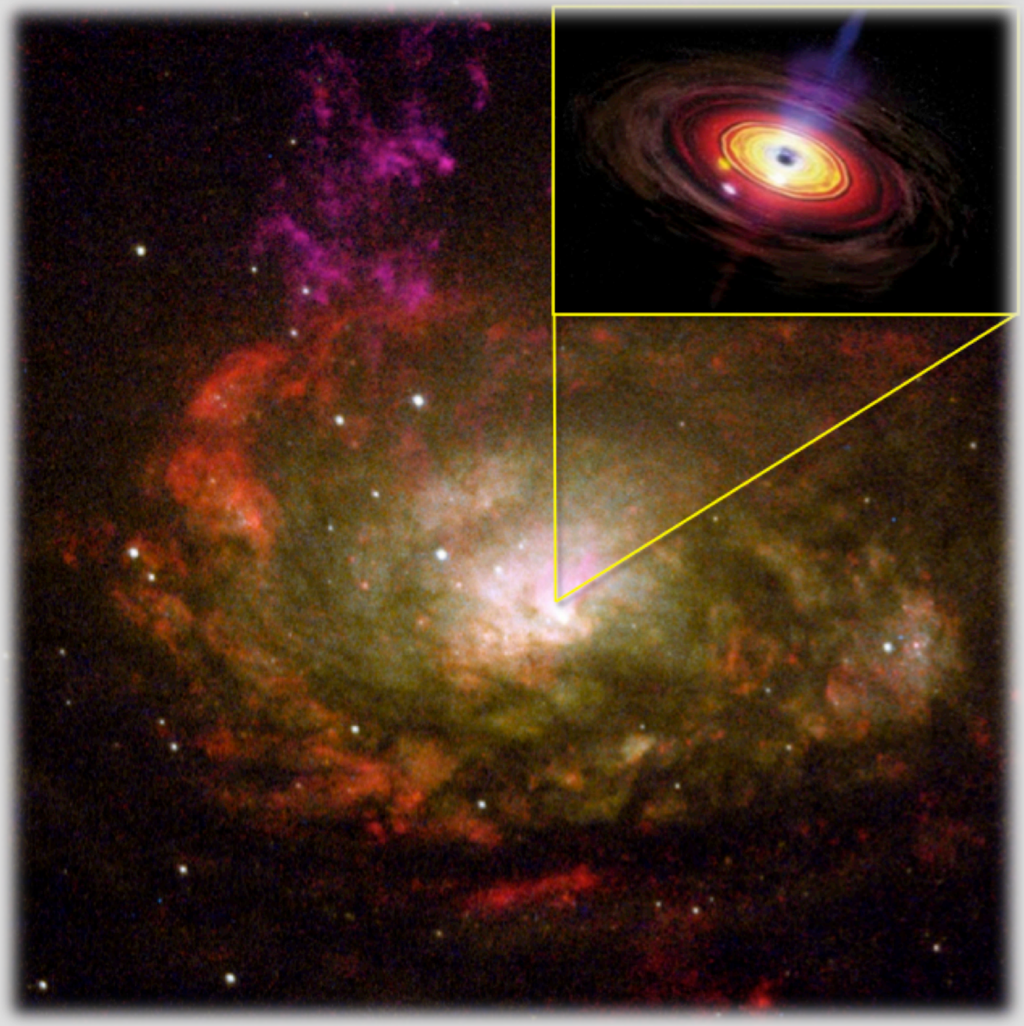


AGN-Galaxy Connection

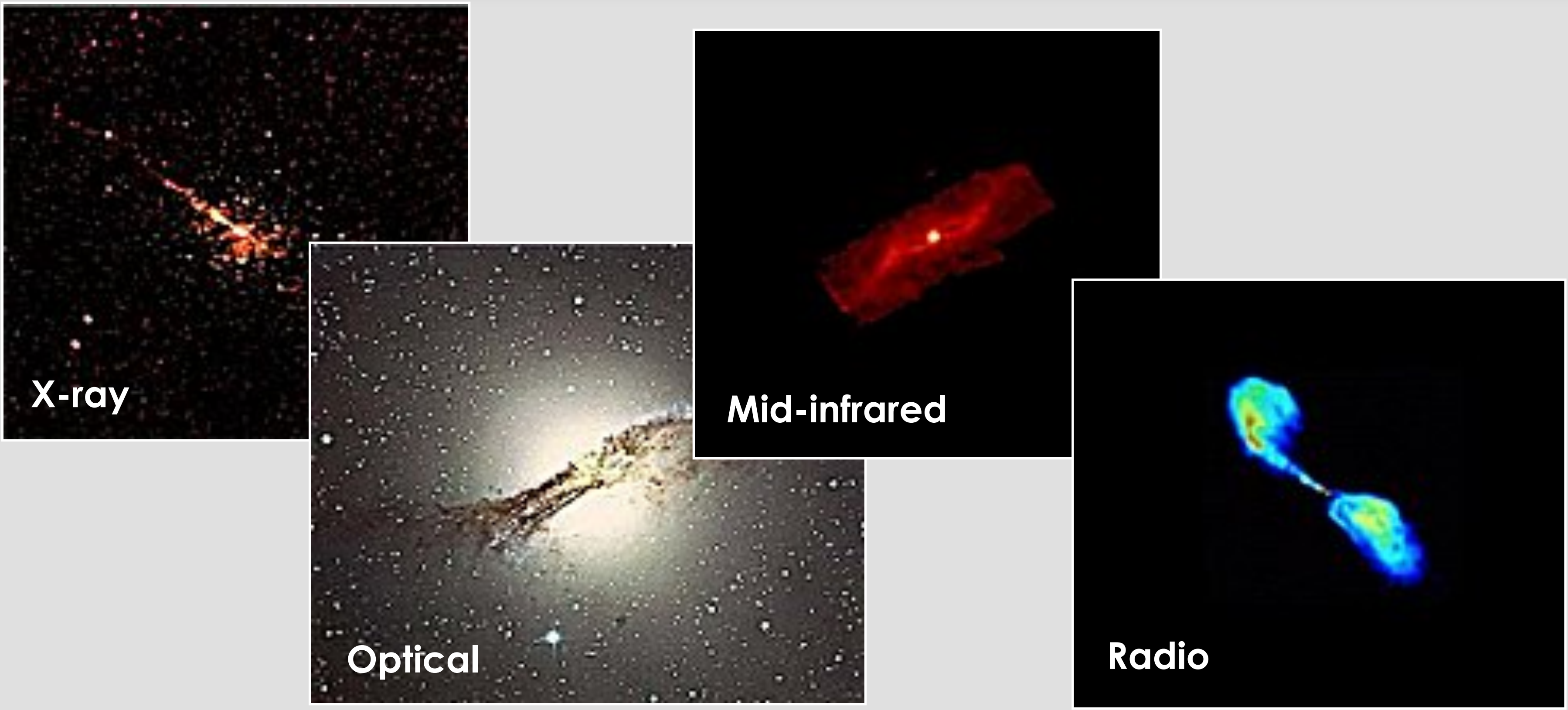
- L_{AGN}-SFR may correlate at bright end but ***not*** at faint end
  - At least two AGN (& SF) triggering mechanisms?
  - (Shao+2010, Lutz+2010, Rosario+2012)
- L_{AGN}-SFR correlate *on average* including intermediate luminosities (smoothing over duty cycle)
  - Universal fraction of gas goes onto BH (but variability)
  - (Mullaney+2012, Chen+2013)
- Connection may depend on many parameters:
  - (AGN) Luminosity, Redshift, Environment, N_H, etc.
  - → It is not sufficient to simply identify AGNs, need more info!

Important questions

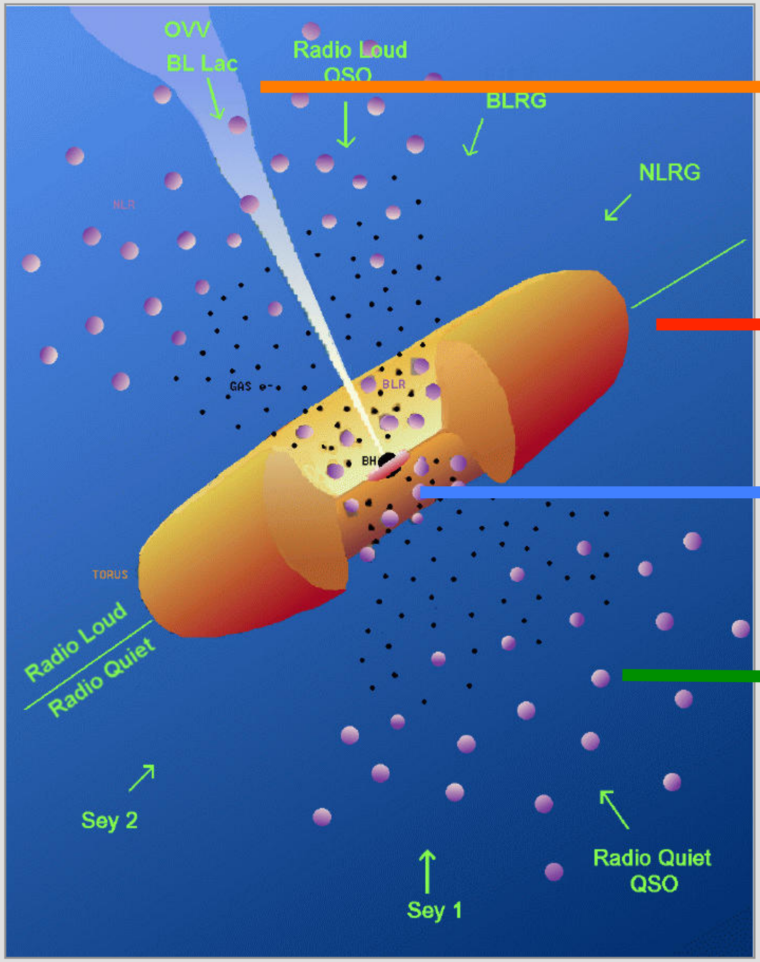
- What is the *multiscale* connection between the growth of stars and black holes in galaxies?
- What is the main triggering/feedback mechanism for AGN?
- Is there redshift evolution in our ability to find AGN?



AGN Identification



AGN Unified Model



(Antonucci 1984; Urry & Padovani 1995)

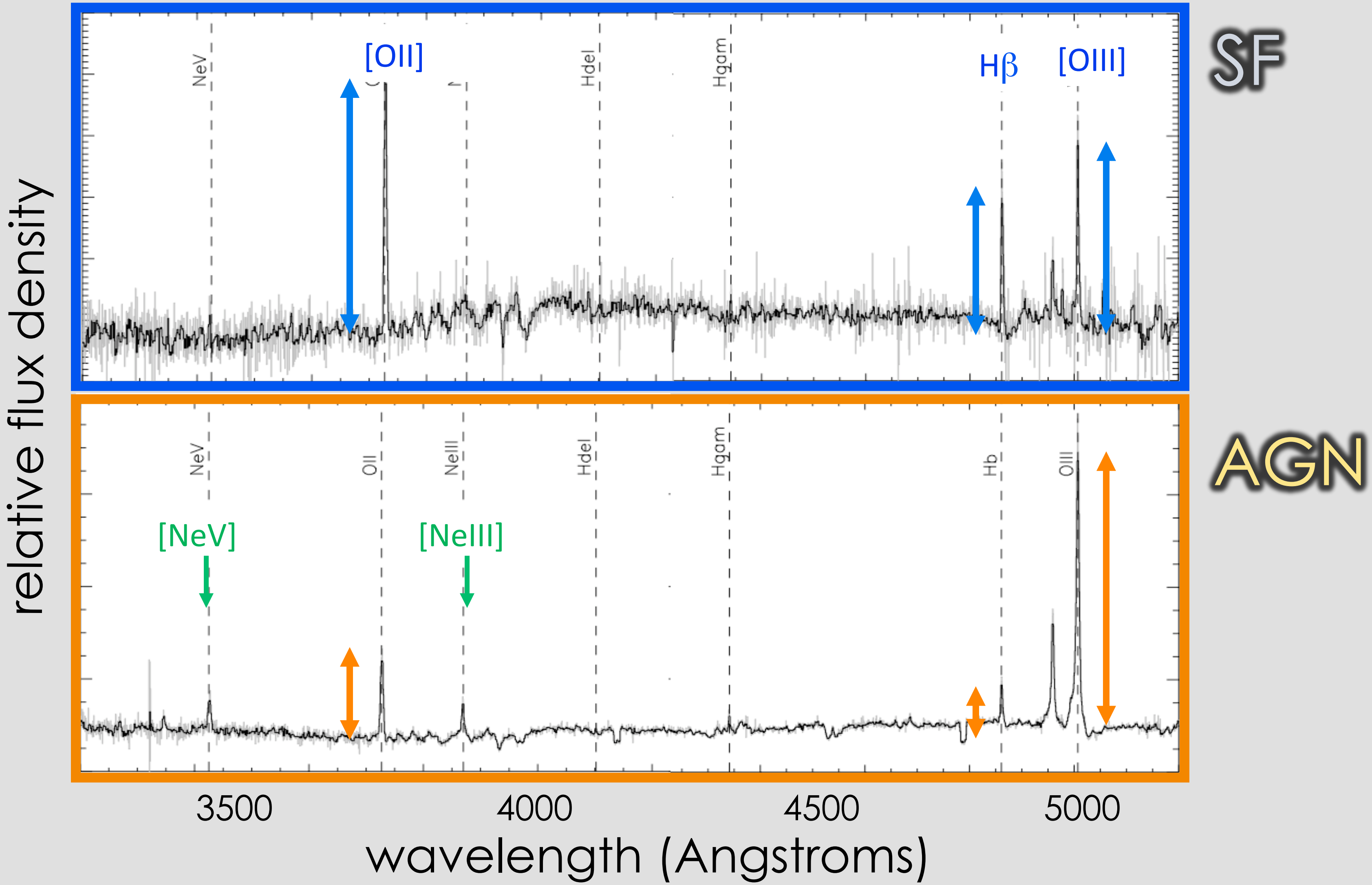
1.4 GHz / FIR
(radio-excess;
Del Moro+12)

IRAC colors
(Stern+05; Donley+07)

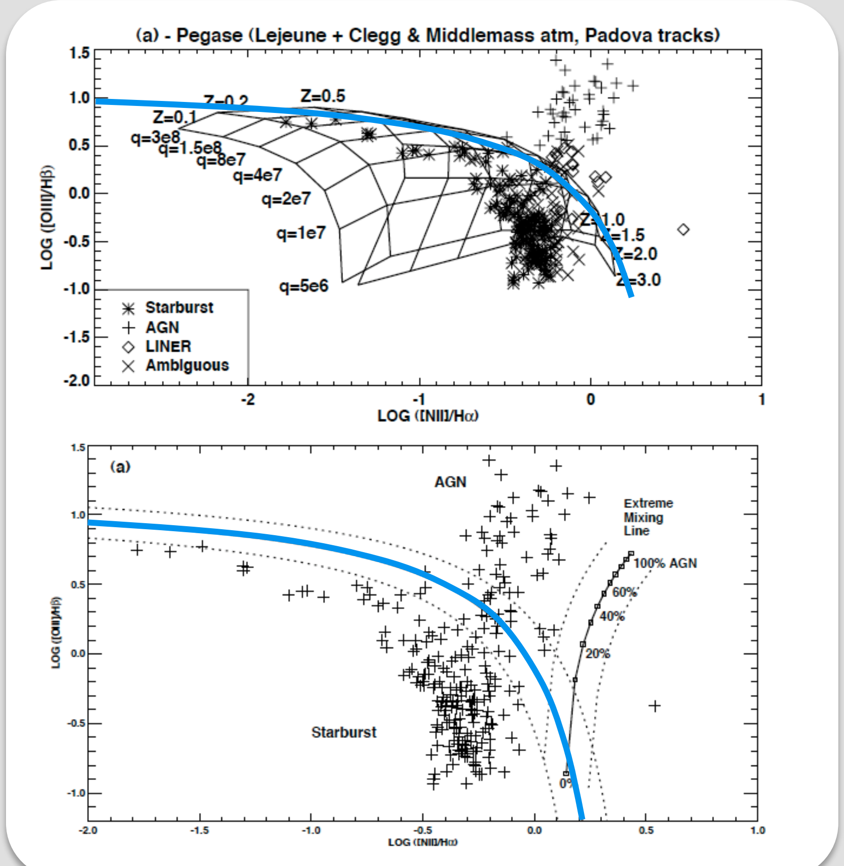
L_X(2-10keV) > 10^{42} erg/s
(Bauer+04)

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

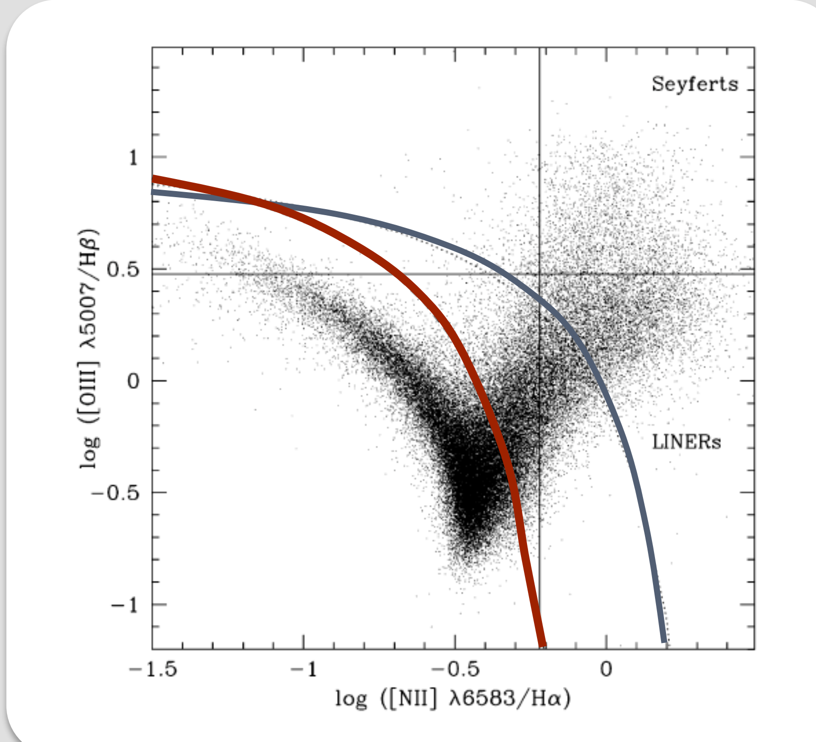
Example Spectra (stacks)



BPT Diagnostic (Baldwin, Phillips & Terlevich 81)



Kewley et al 2001



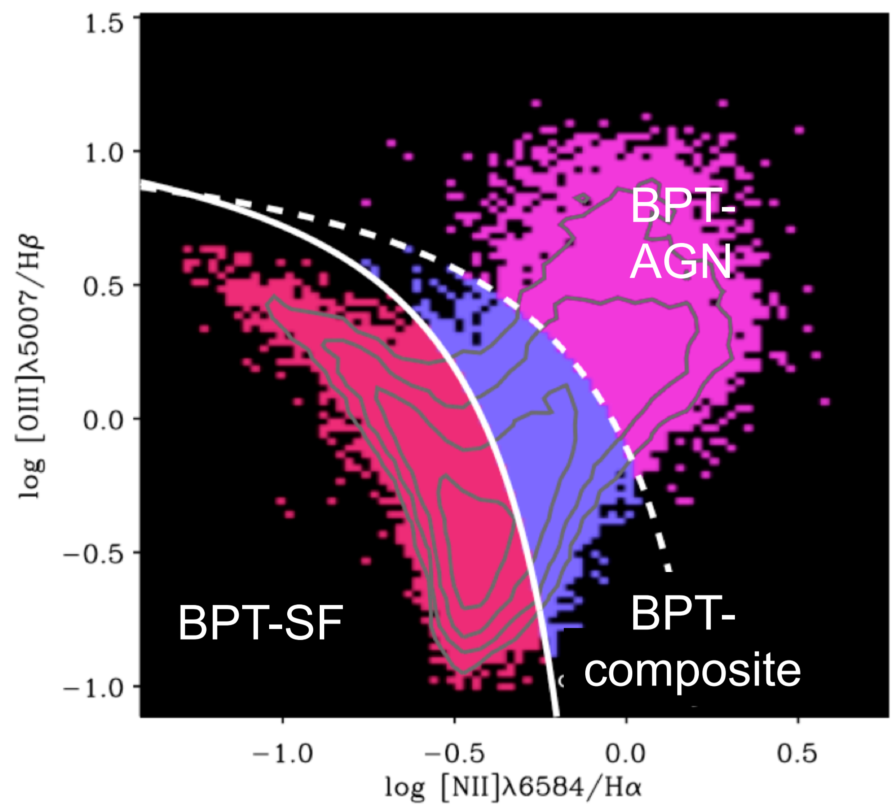
SDSS <z> = 0.1 galaxies
Kauffmann et al 2003

(also Stasinska et al 2006; Kewley et al 2006)

BPT Diagnostic (Baldwin, Phillips & Terlevich 81)

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

2- Useable out to z~0.4 with optical spectra

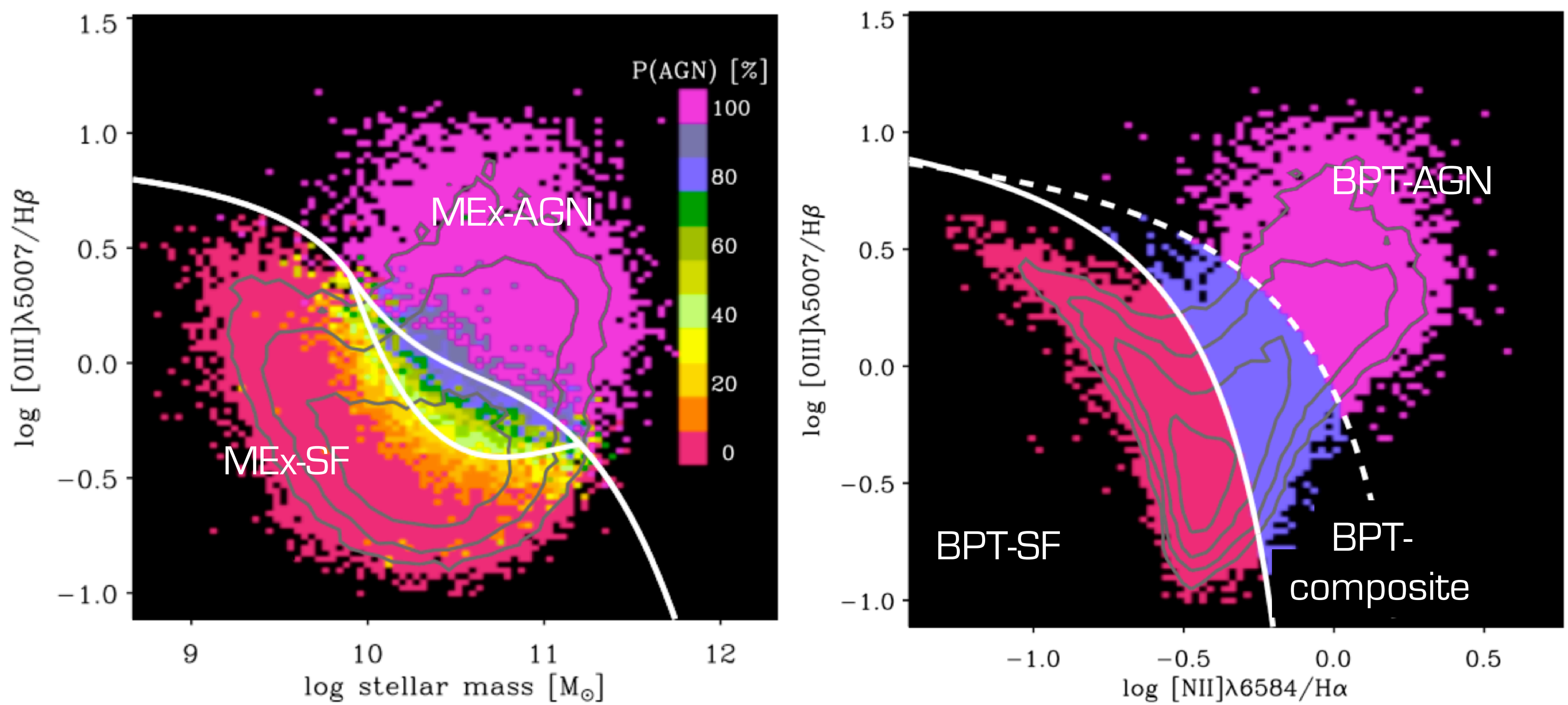


(adapted from Juneau+ 2011)

Mass-Excitation (MEx) Diagnostic

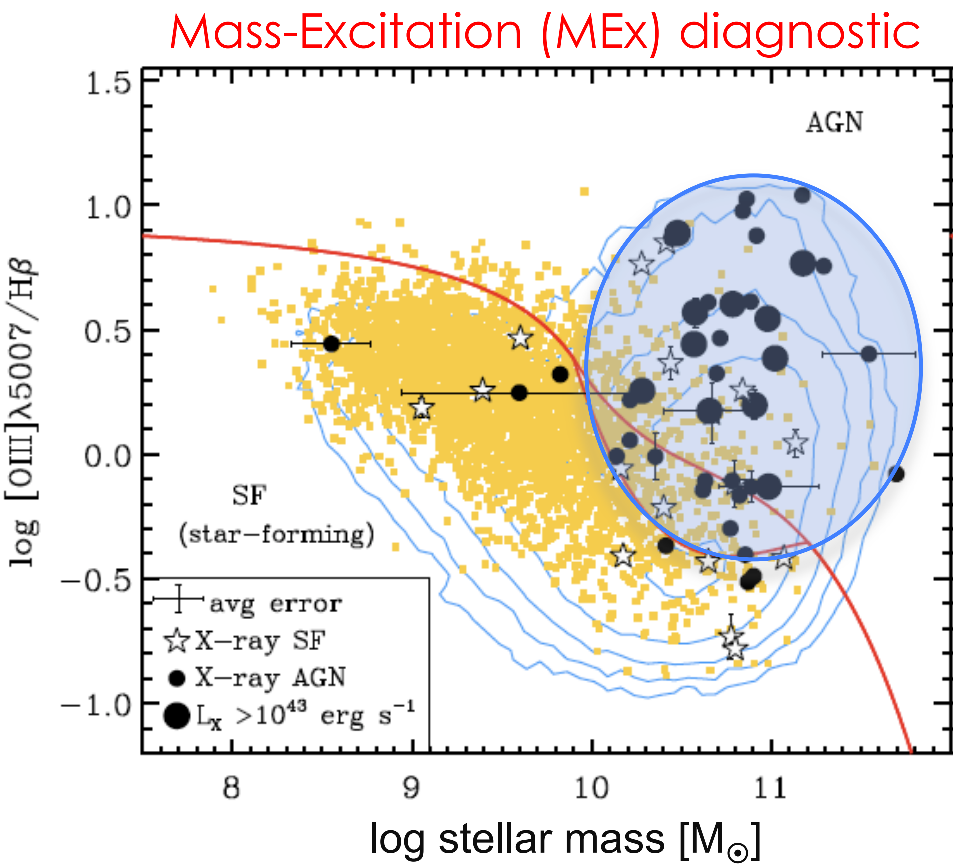
1- Empirical dividing Lines (from >100,000 SDSS galaxies at 0.05<z<0.1)

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



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

MEx confirmed with X-rays



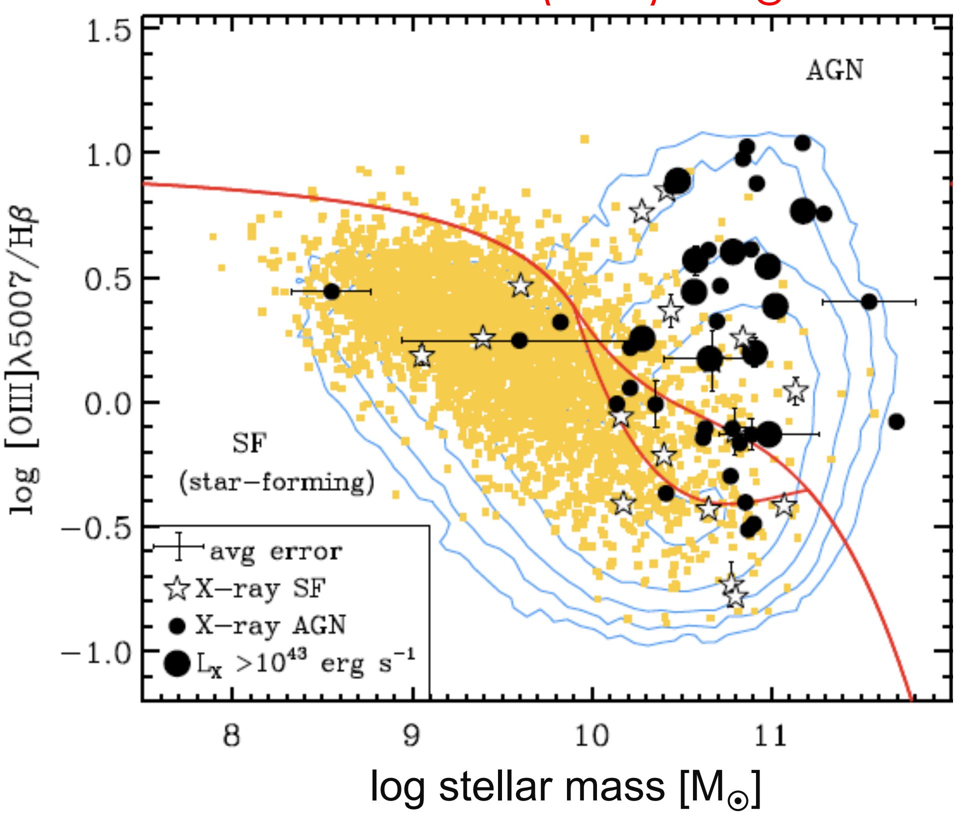
- MEx diagram identifies 85% of X-AGN that have emission lines

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)

Juneau et al. 2011

MEx confirmed with X-rays

Mass-Excitation (MEx) diagnostic



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- Additional AGN **missed or misclassified in the X-rays**

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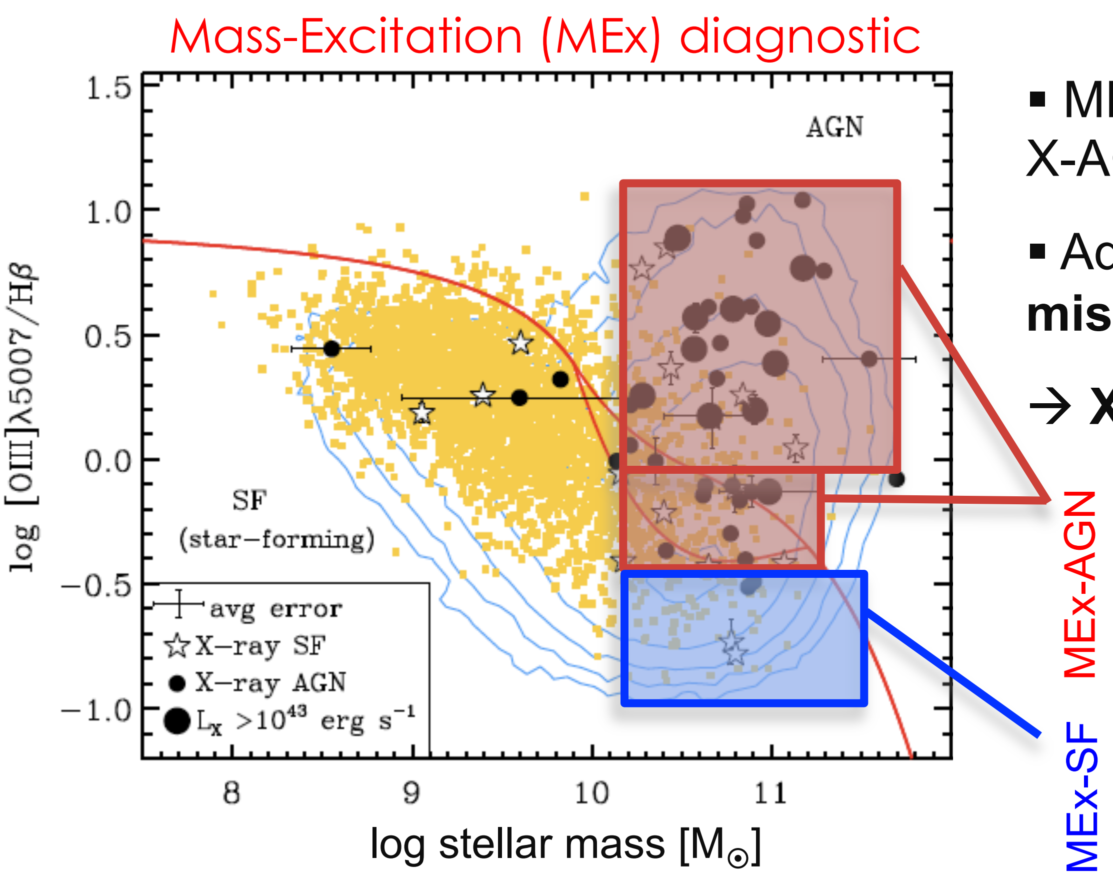

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- Additional AGN **missed or misclassified in the X-rays**

→ **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**

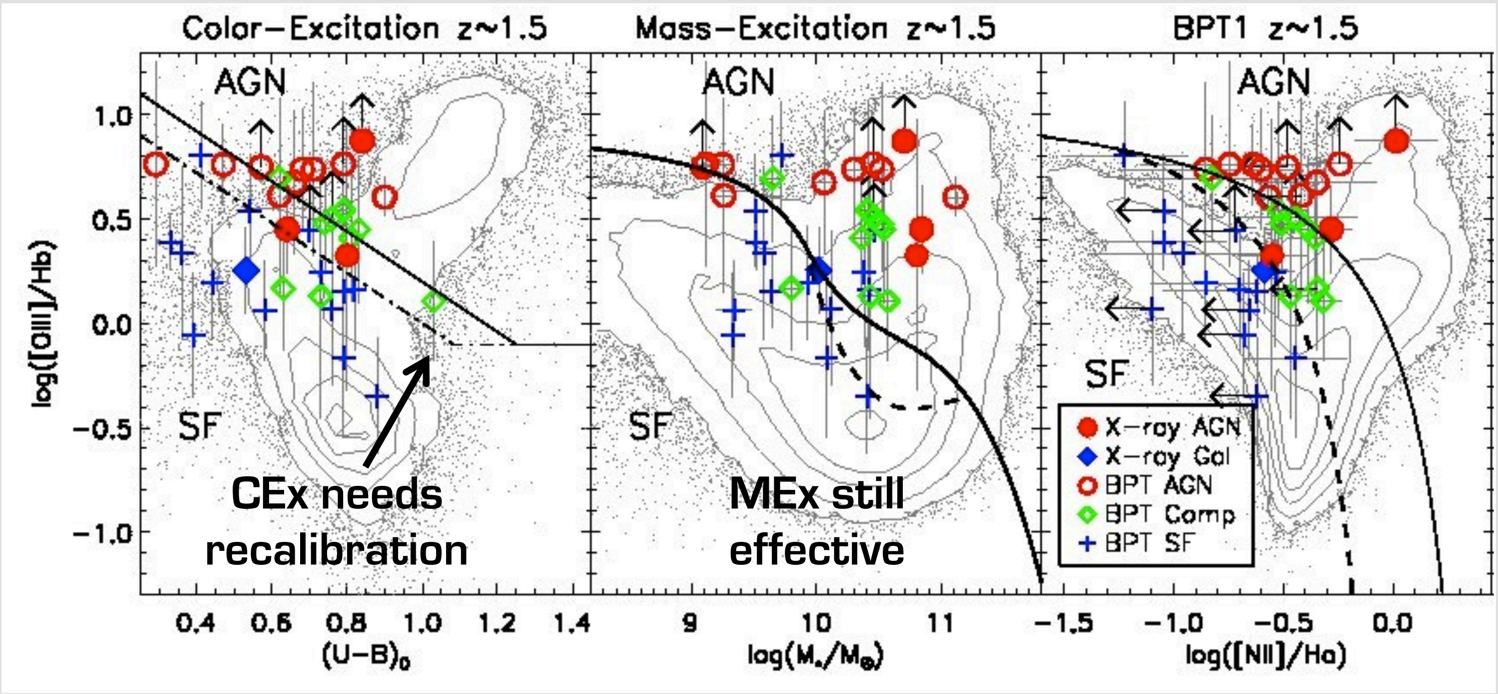
<u>Sample:</u> 3,386 galaxies at **0.3<z<1** with [OIII]λ5007, Hβ & stellar mass in **GOODS-North** & **EGS**
<u>Chandra X-ray:</u> 2 Msec in GOODS-N (Alexander+ 03); 200 ksec in EGS (Nandra+05, Laird+09)

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)



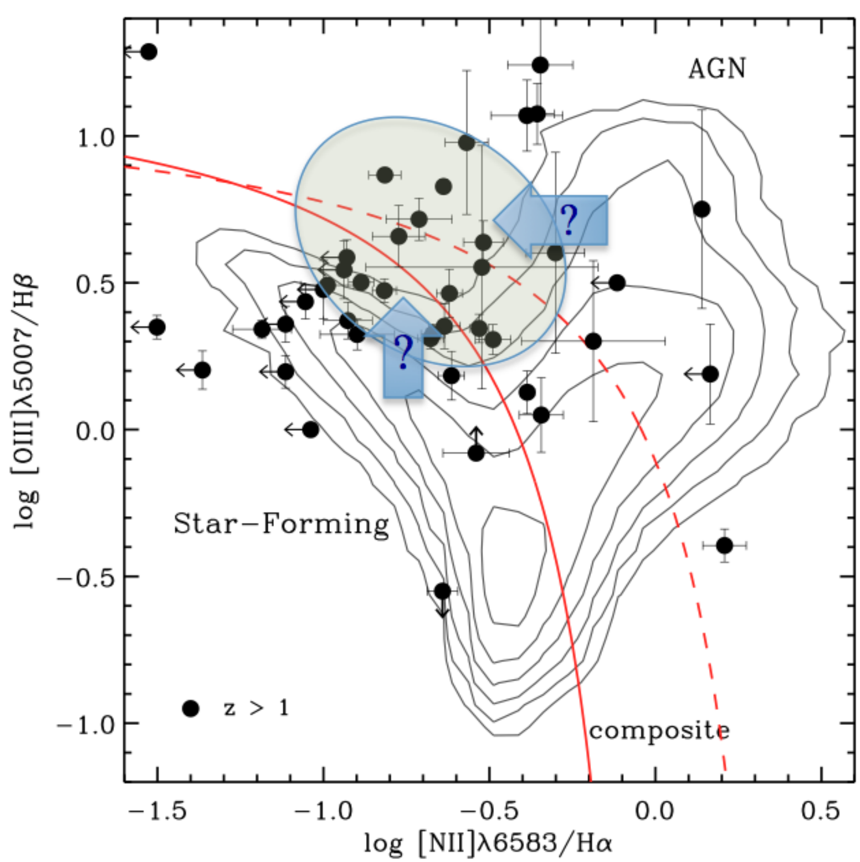
~50% host X-ray/BPT AGNs!

Trump et al (2013)

MEx Diagnostic Diagram: 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 effect (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?** (Kewley+2013a,b; Newman +2014; Holden+2014

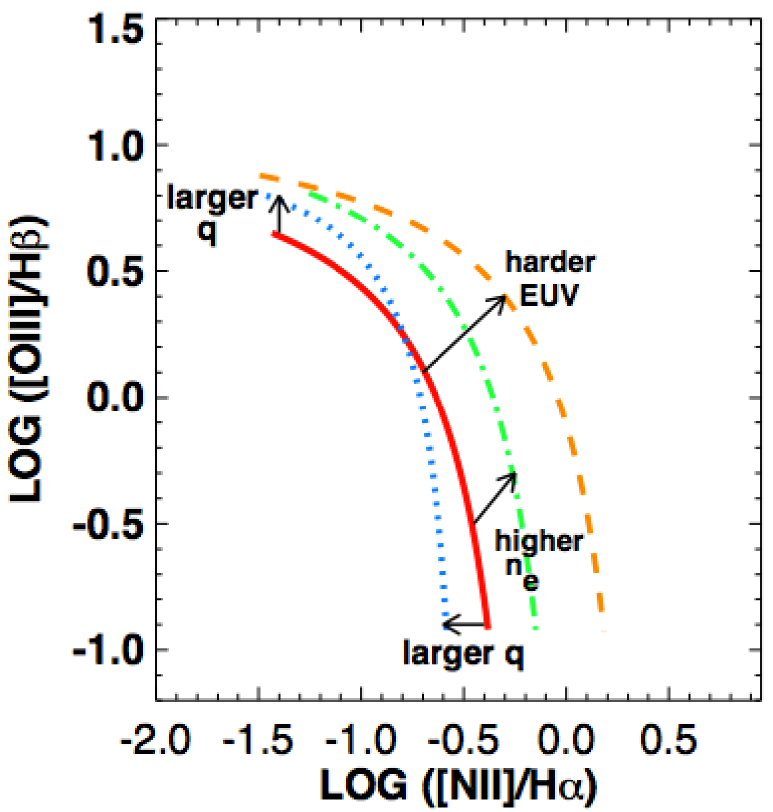
BPT diagnostic at higher redshifts



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?

BPT diagnostic at higher redshifts



Kewley+ 2013a

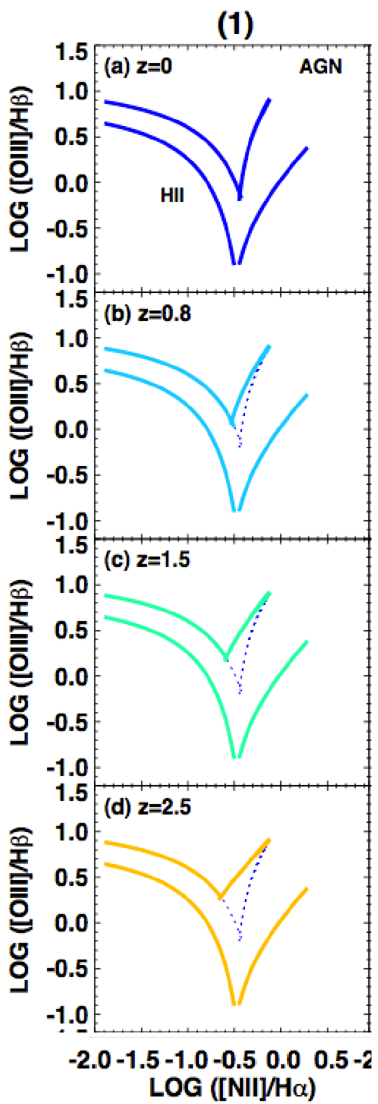
- Changing HII region conditions?

→ 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

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

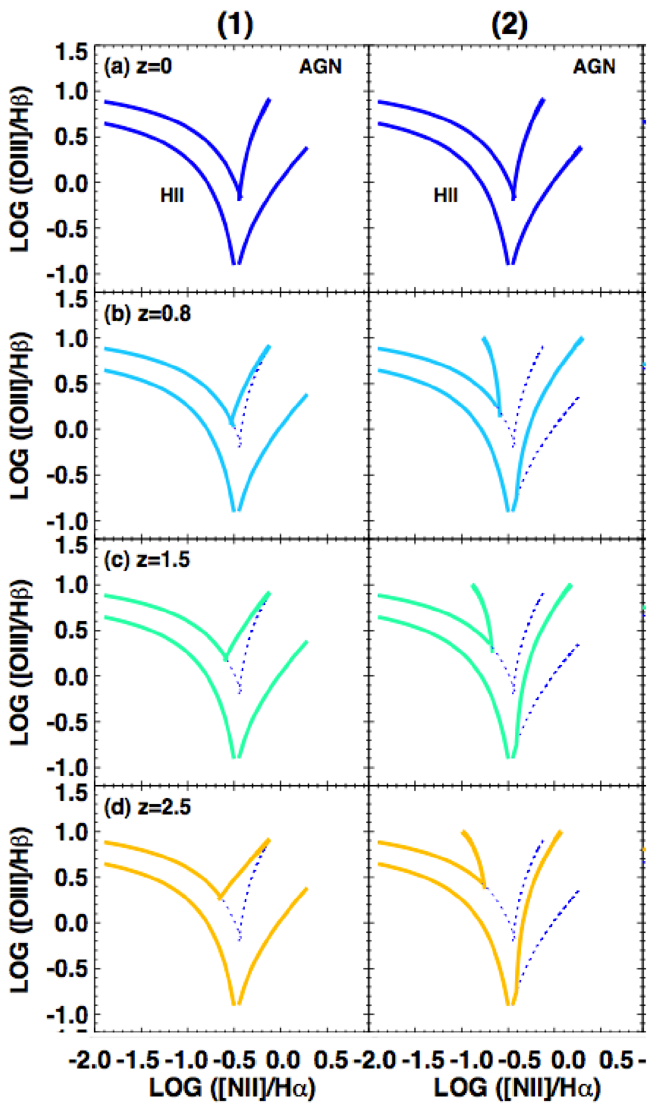
Four scenarios



Scenario 1:

- Normal ISM
- Metal-rich NLRs

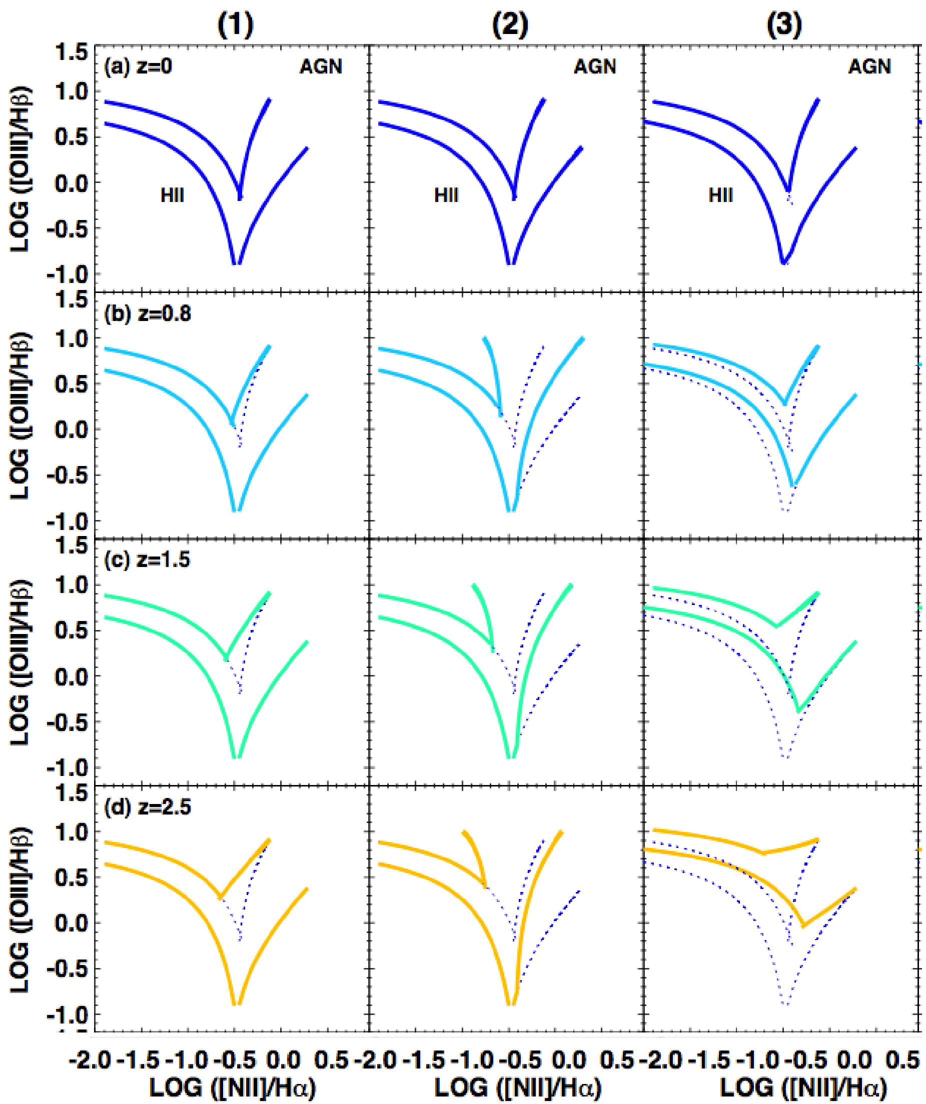
Four scenarios



Scenario 2:

- Normal ISM
- Metal-poor NLRs

Four scenarios

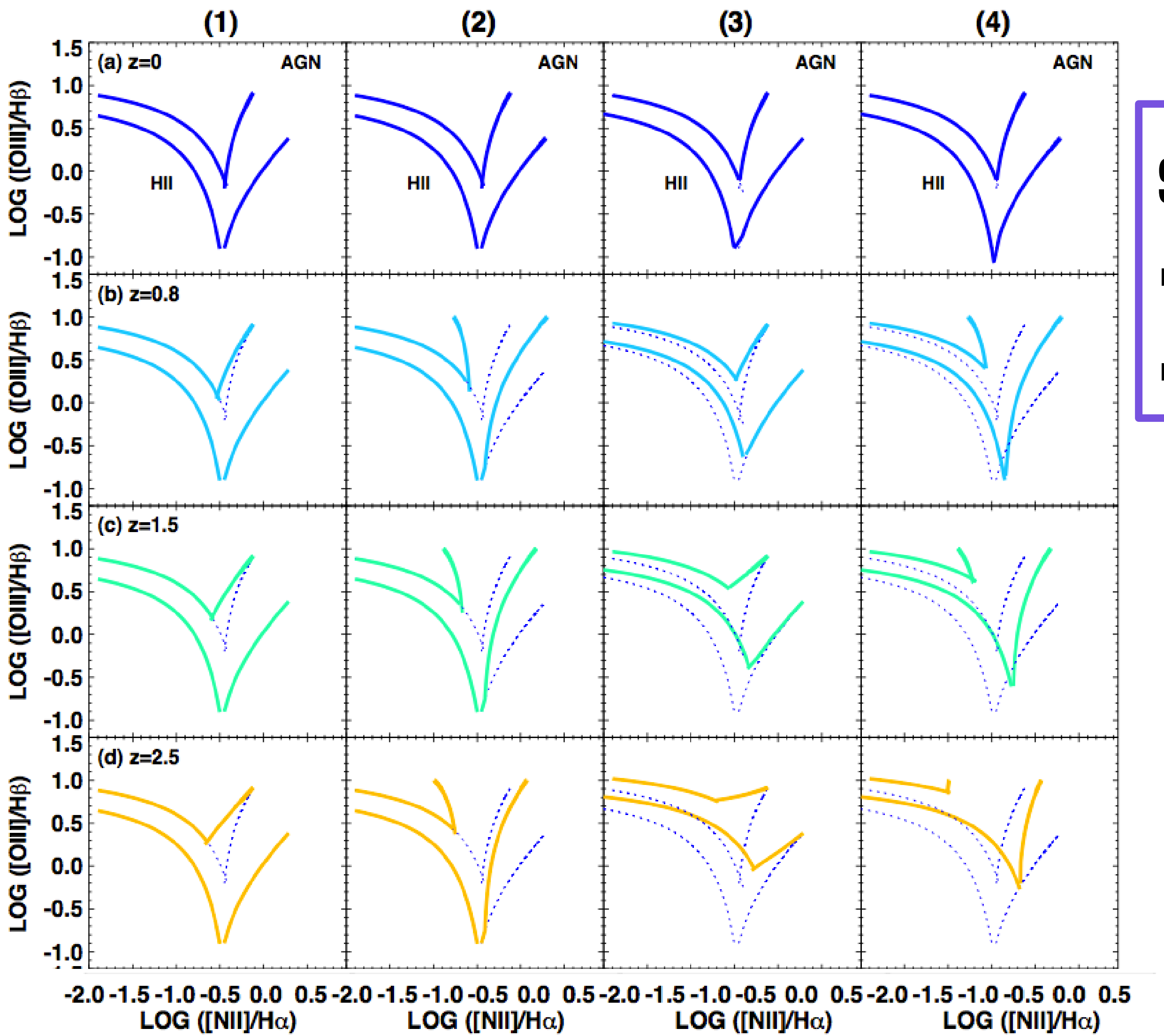


Scenario 3:

- Extreme ISM
- Metal-rich NLRs

Kewley+ 2013a

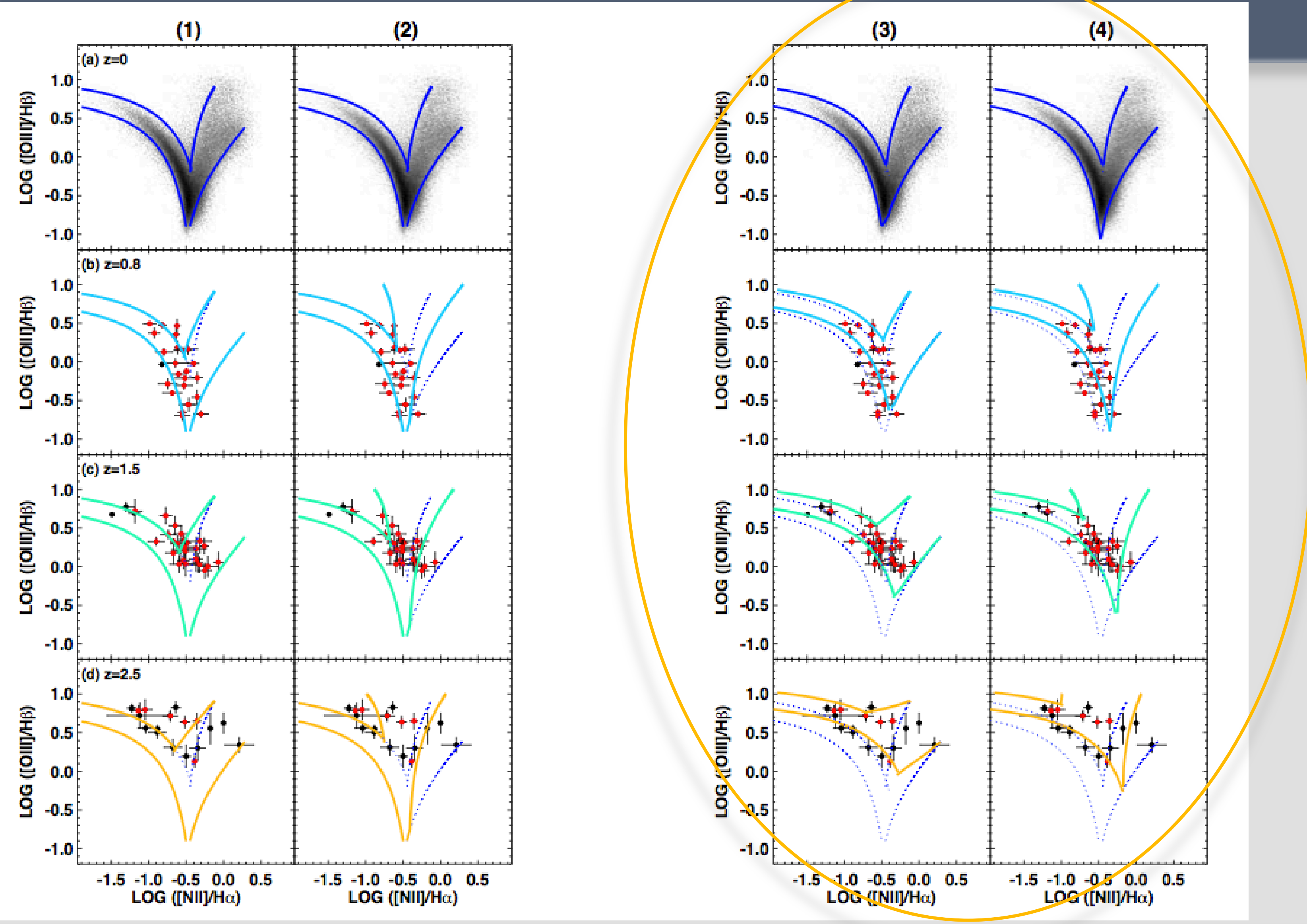
Four scenarios



Scenario 4:

- Extreme ISM
- Metal-poor NLRs

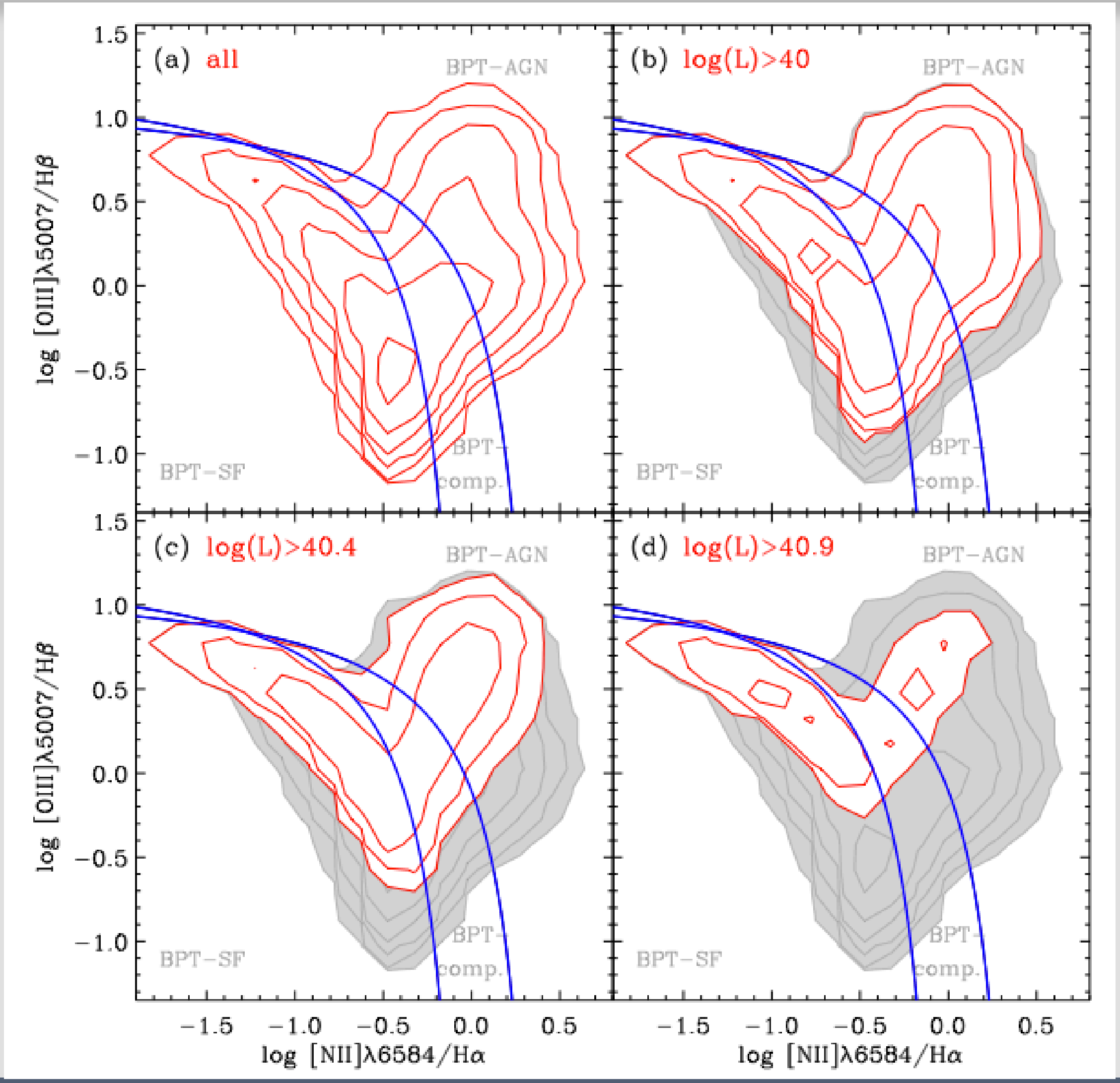
Four scenarios: Can we just overplot some data?



Kewley+ 2013b

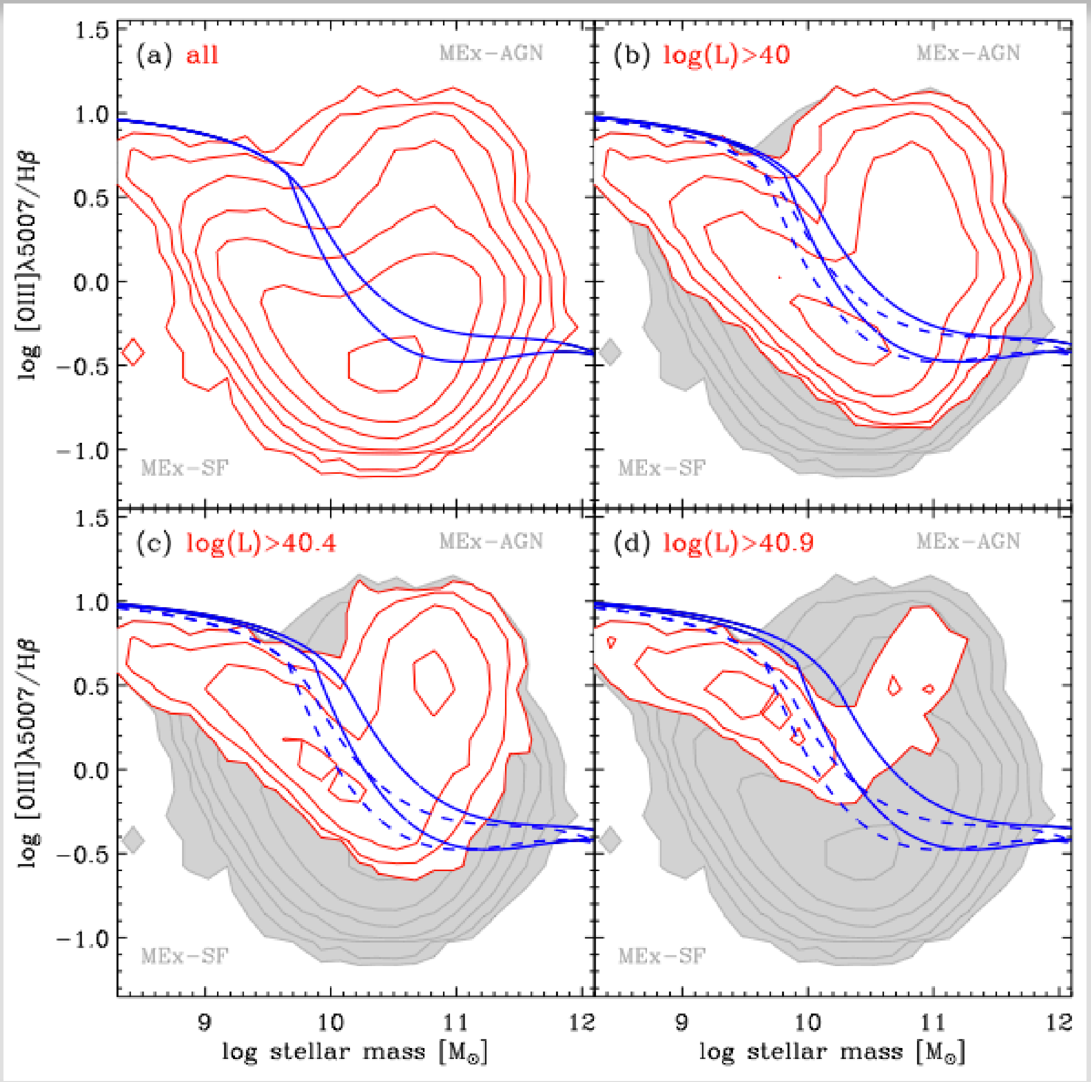
Emission-line Luminosity Threshold

1) BPT



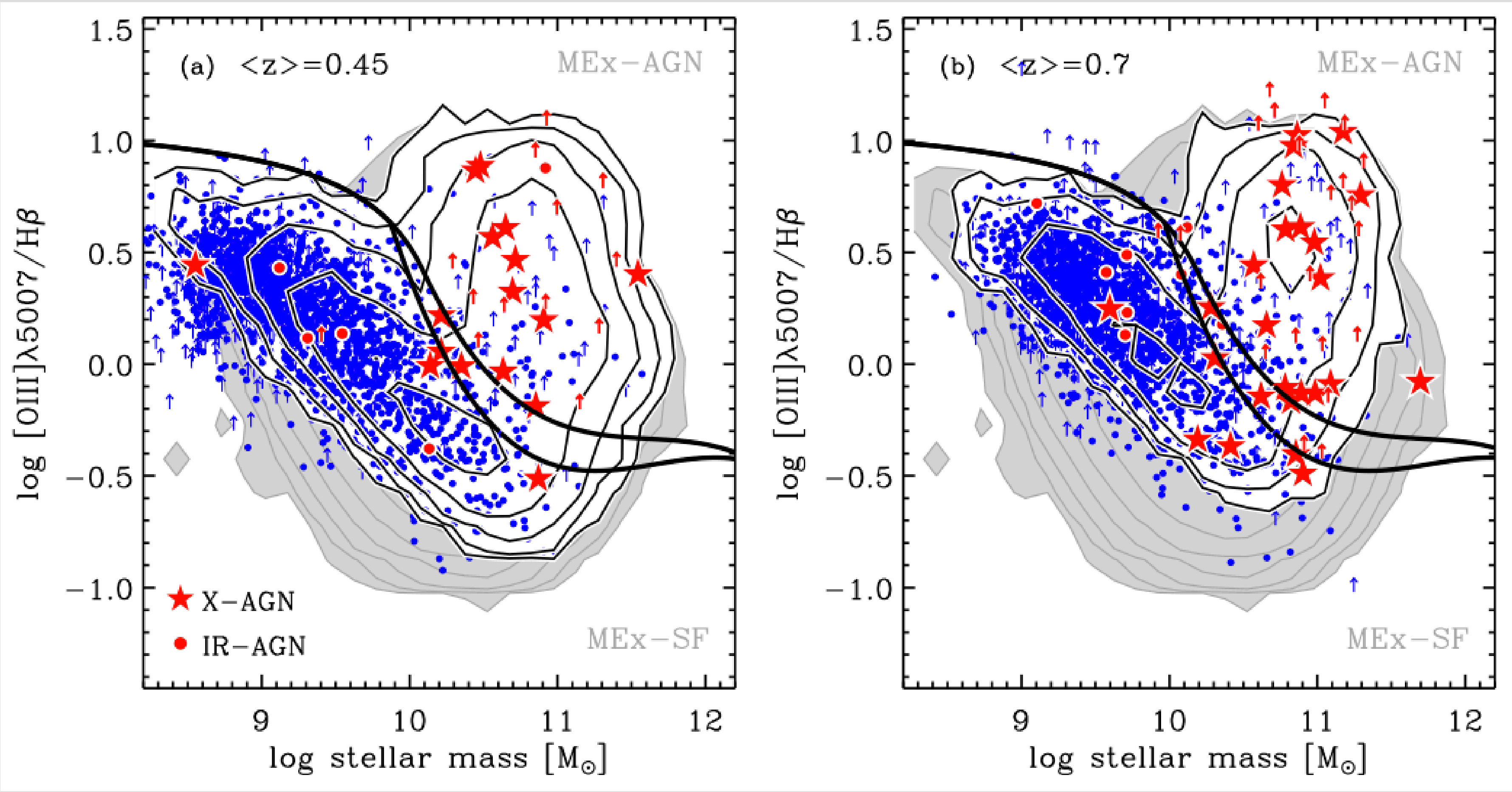
Emission-line Luminosity Threshold

2) MEx



Juneau et al, submitted (arXiv:1403.6832)

Application at 0.3< z <1



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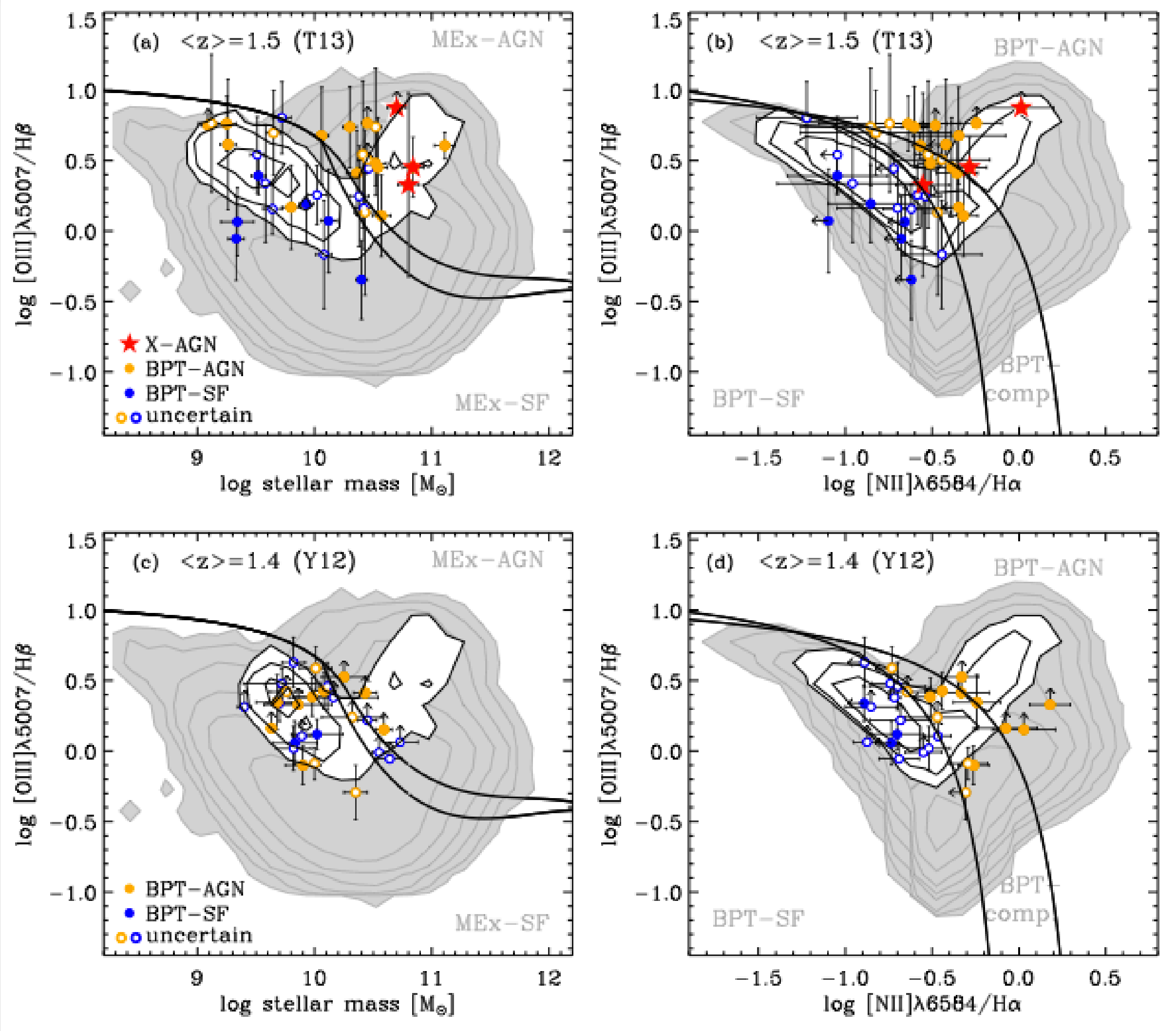
Application at z =1.5



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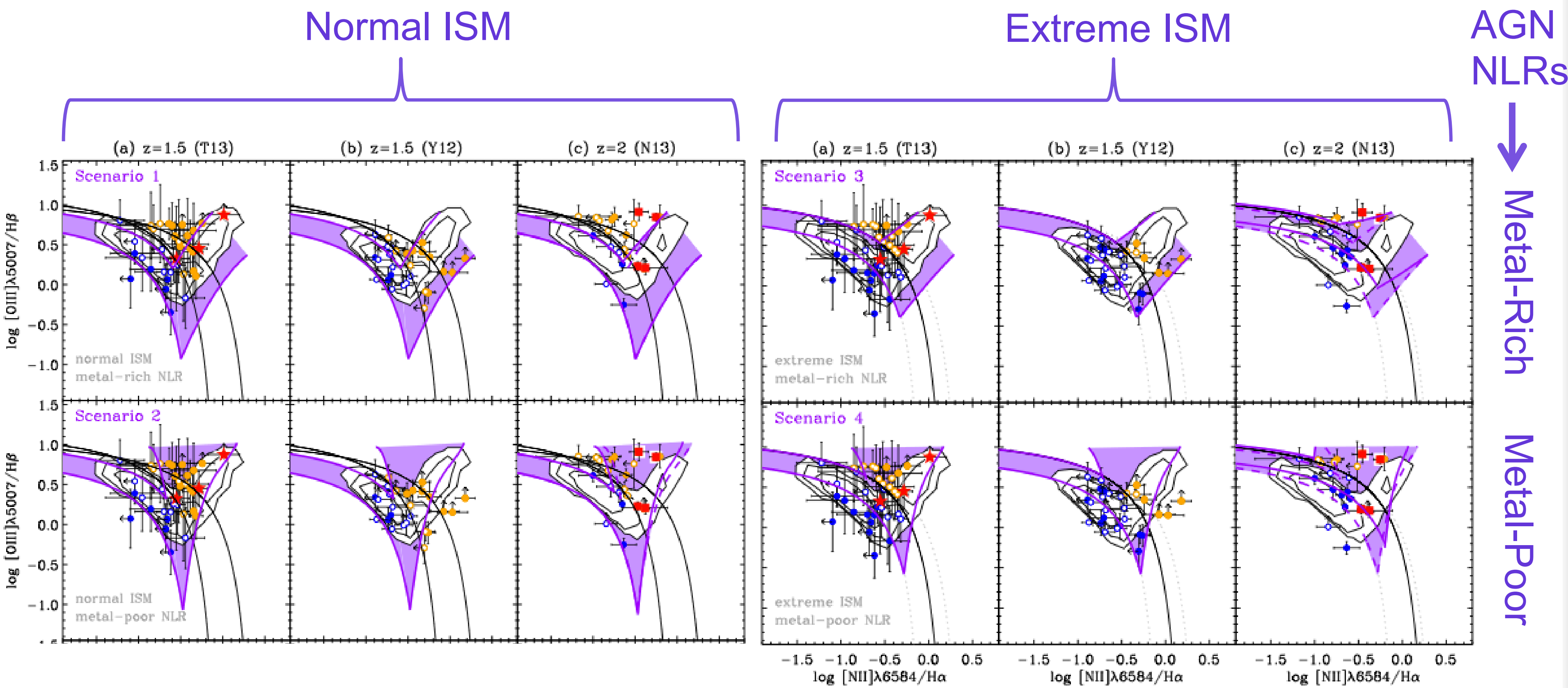
Revising Evolutionary Scenarios



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Take-home points

- Beware of selection effects before being able to assess evolution of "microphysics" (could be overestimated)

- It is possible to find low-z analogs* by carefully cutting an appropriate sample (*check with properties correspond and which ones differ)

- Increasingly important at higher redshifts because of the evolution of the "macrophysics" (general galaxy population) in terms of both (S)SFR and incidence of AGN (which was much higher in the past)

AGN Triggering vs. Feedback

- Important presence of AGN alongside star formation in galaxies (longer periods of activity; e.g., Juneau+2013)
  - range of AGN luminosities from weak to Seyfert-regime w/ very few Quasars

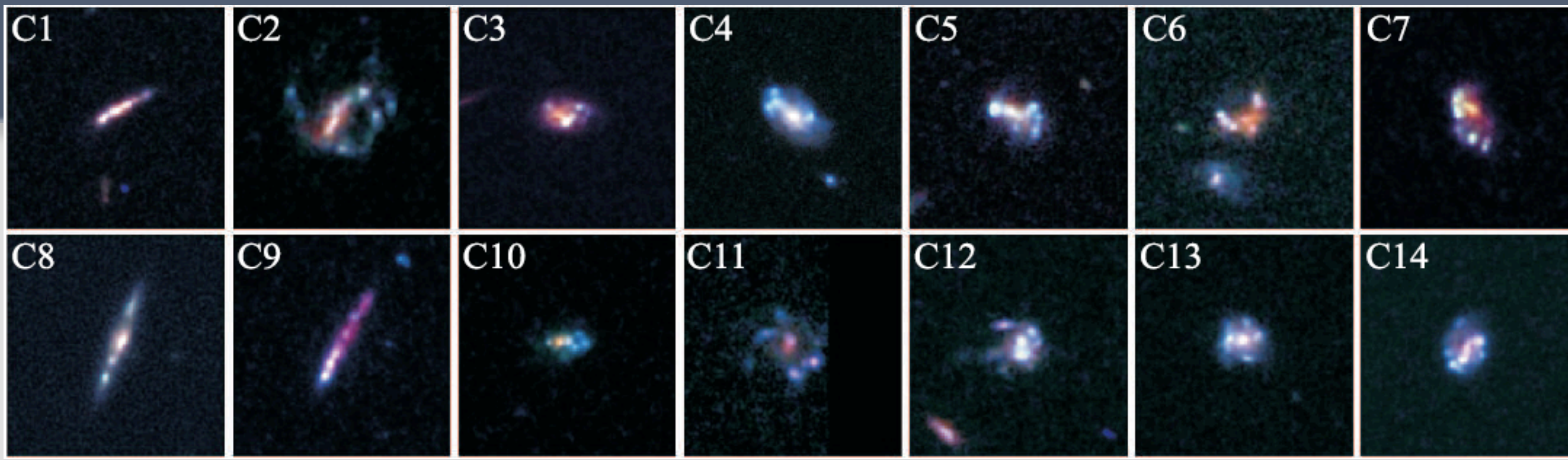
1) Triggering:

- Affected by the properties of interstellar gas (dynamics, physical state, etc.) – The case of Clumpy (unstable) disk galaxies

2) Feedback:

- What are the effects on star formation?
  - Negative feedback expected from some models; but not convincingly observed

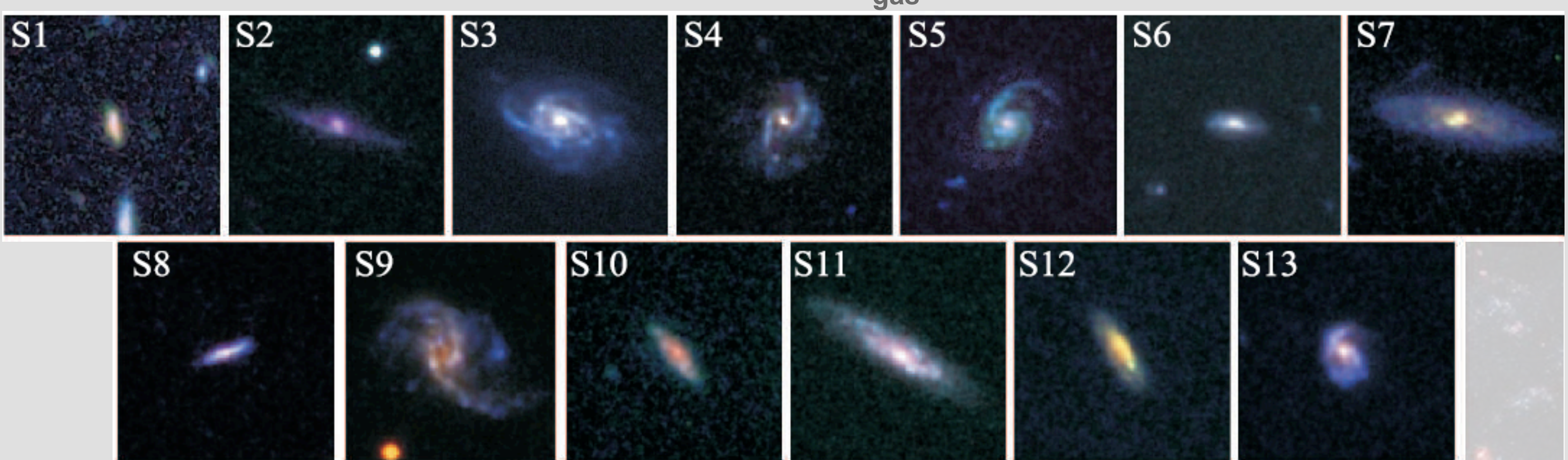
Clumpy vs. Stable disks



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

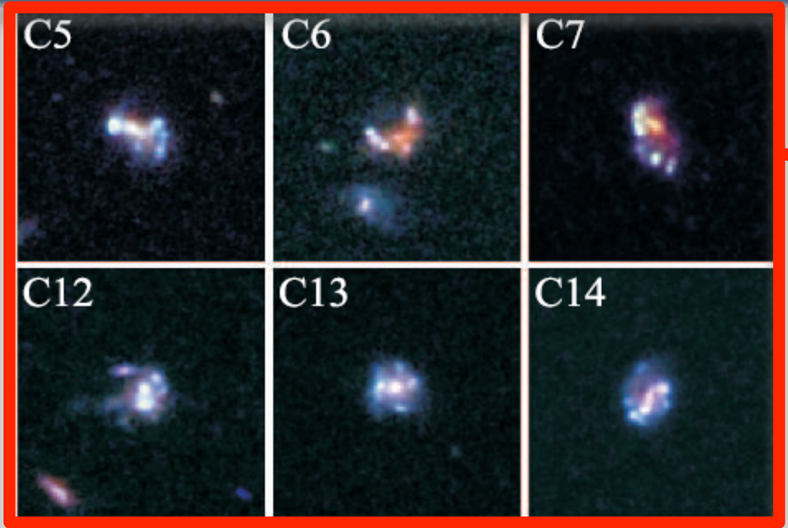
In GOODS-South, redshift and mass-matched, $M^* \sim$ few 10^{10}

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

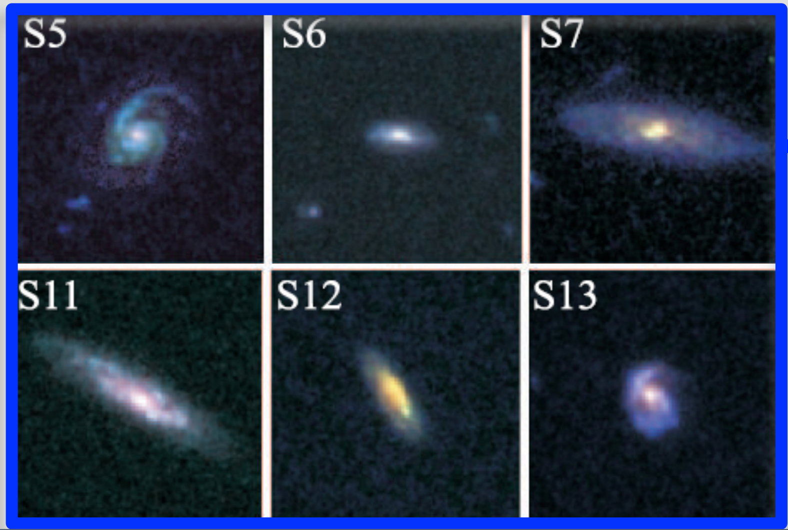


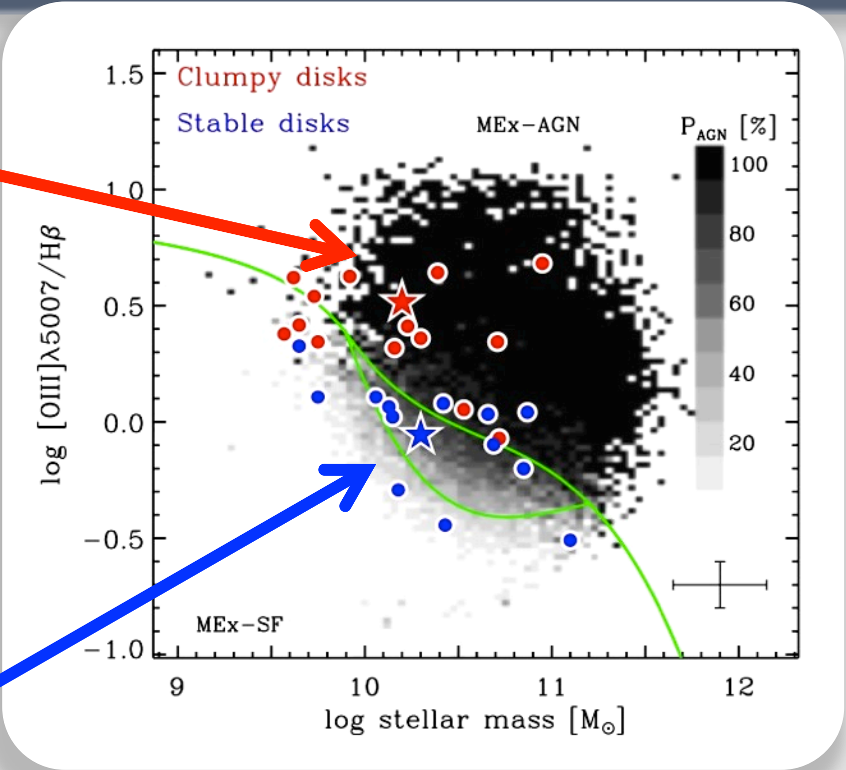
Clumpy disks fuel BH growth

Clumpy (unstable) disks



Stable disks

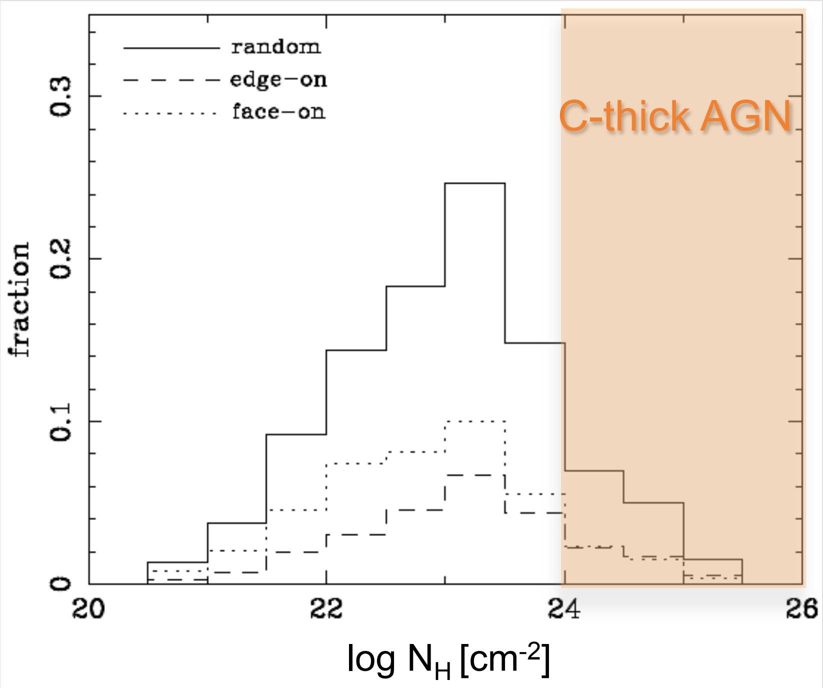


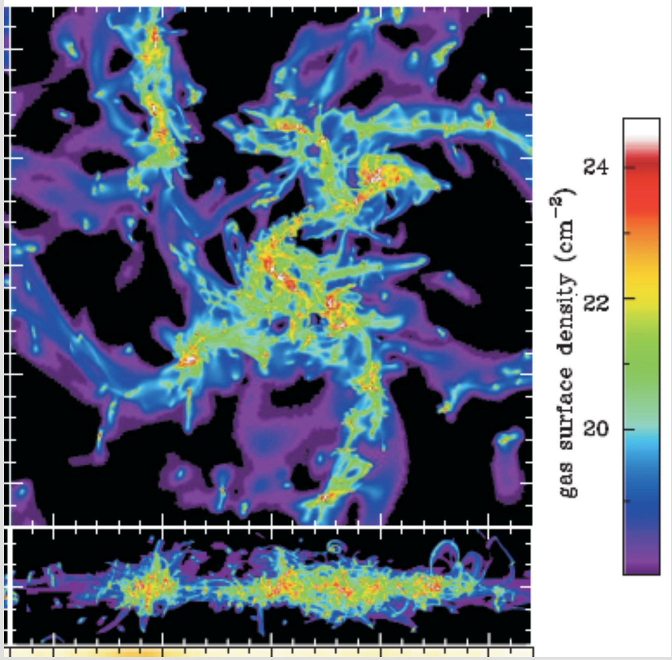


- New mode of BH growth in violently unstable disks (Bournaud+11; Bournaud, Juneau+ 2012)
- Confirmed with X-ray stacking

Absorption by Gas-Rich Hosts

At higher redshifts: disk galaxies were gas-rich (Daddi+10; Tacconi +10), more unstable (clumpy morphology; Elmegreen+09) → expect high obscuring columns along certain LOS

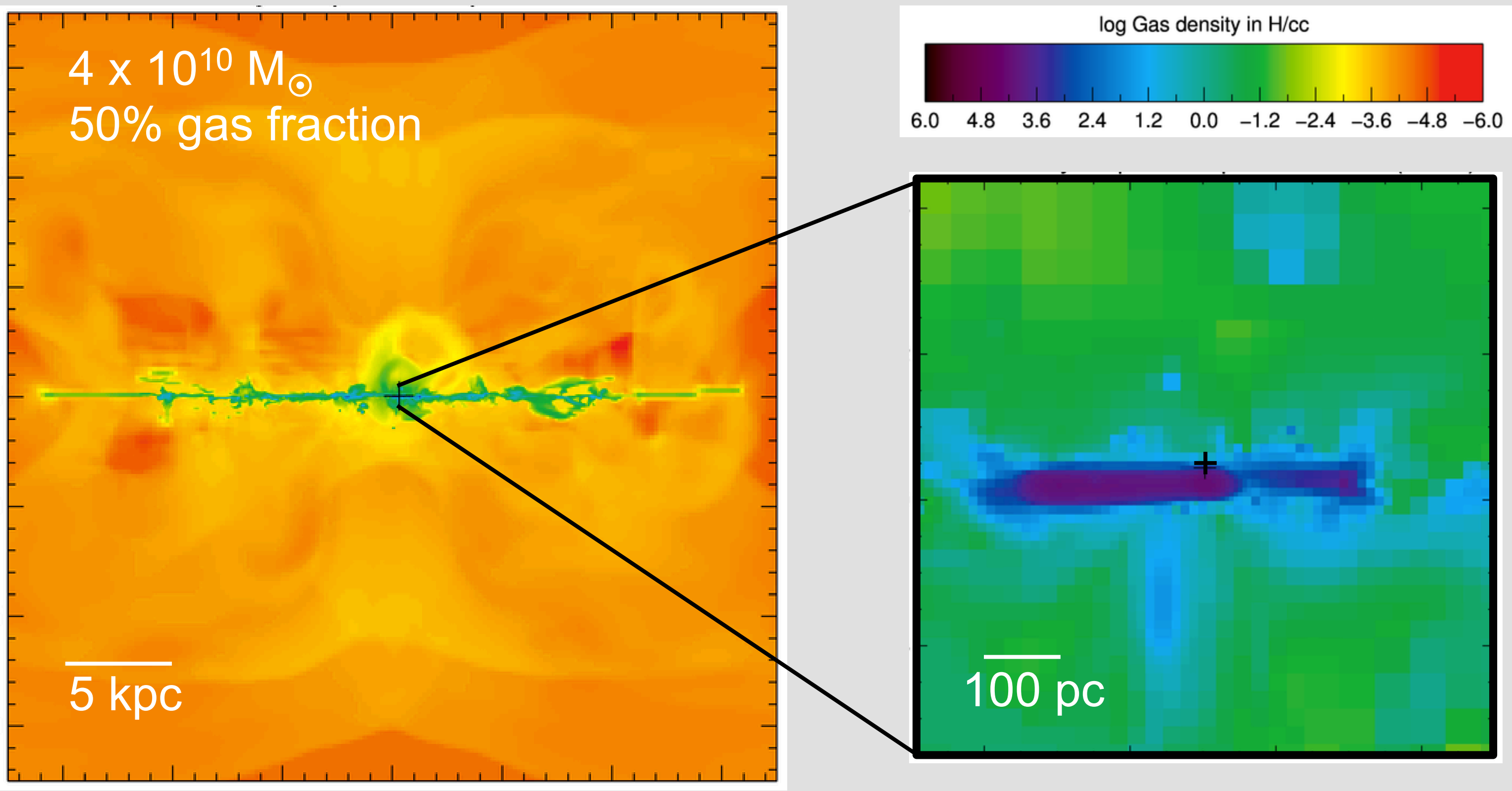




Bournaud et al. 2011

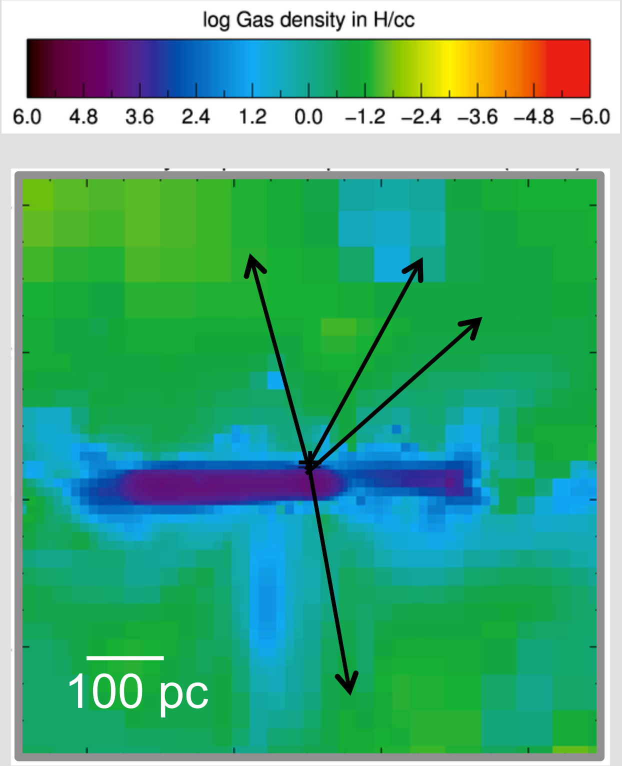
Feedback

- AMR simulations w/ thermal feedback (Gabor+13)
- Add AGN photoionization (Orianne Roos; CEA-Saclay)

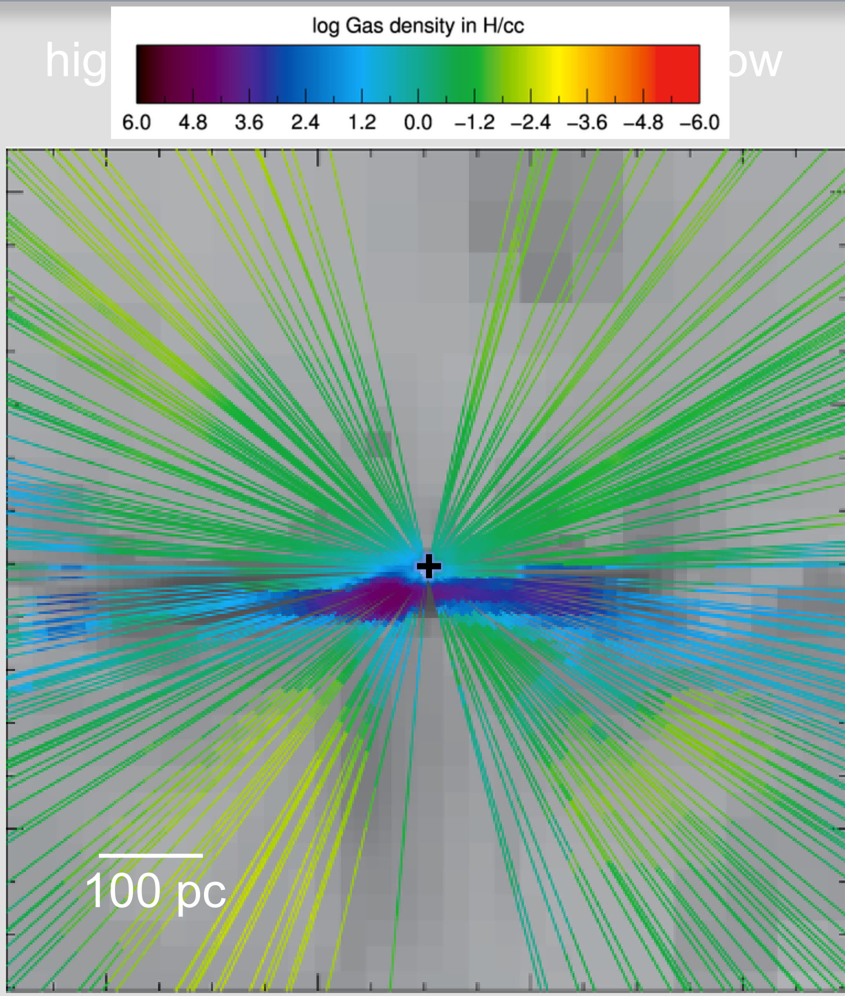


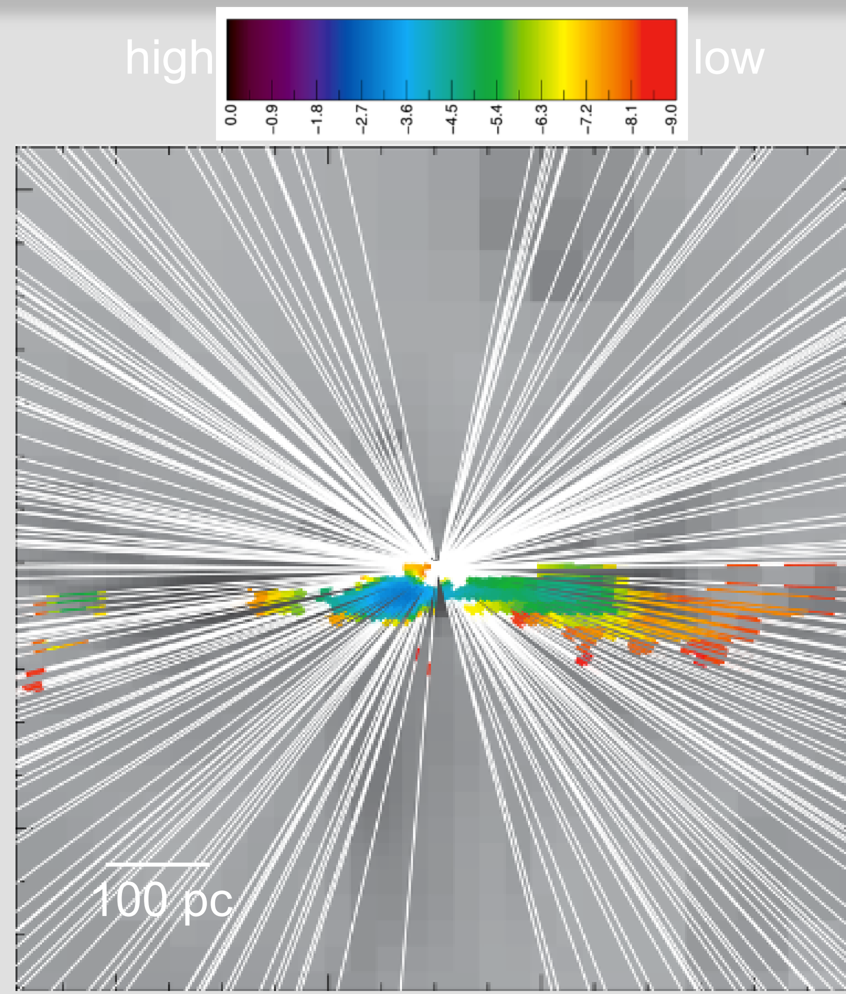
Feedback

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

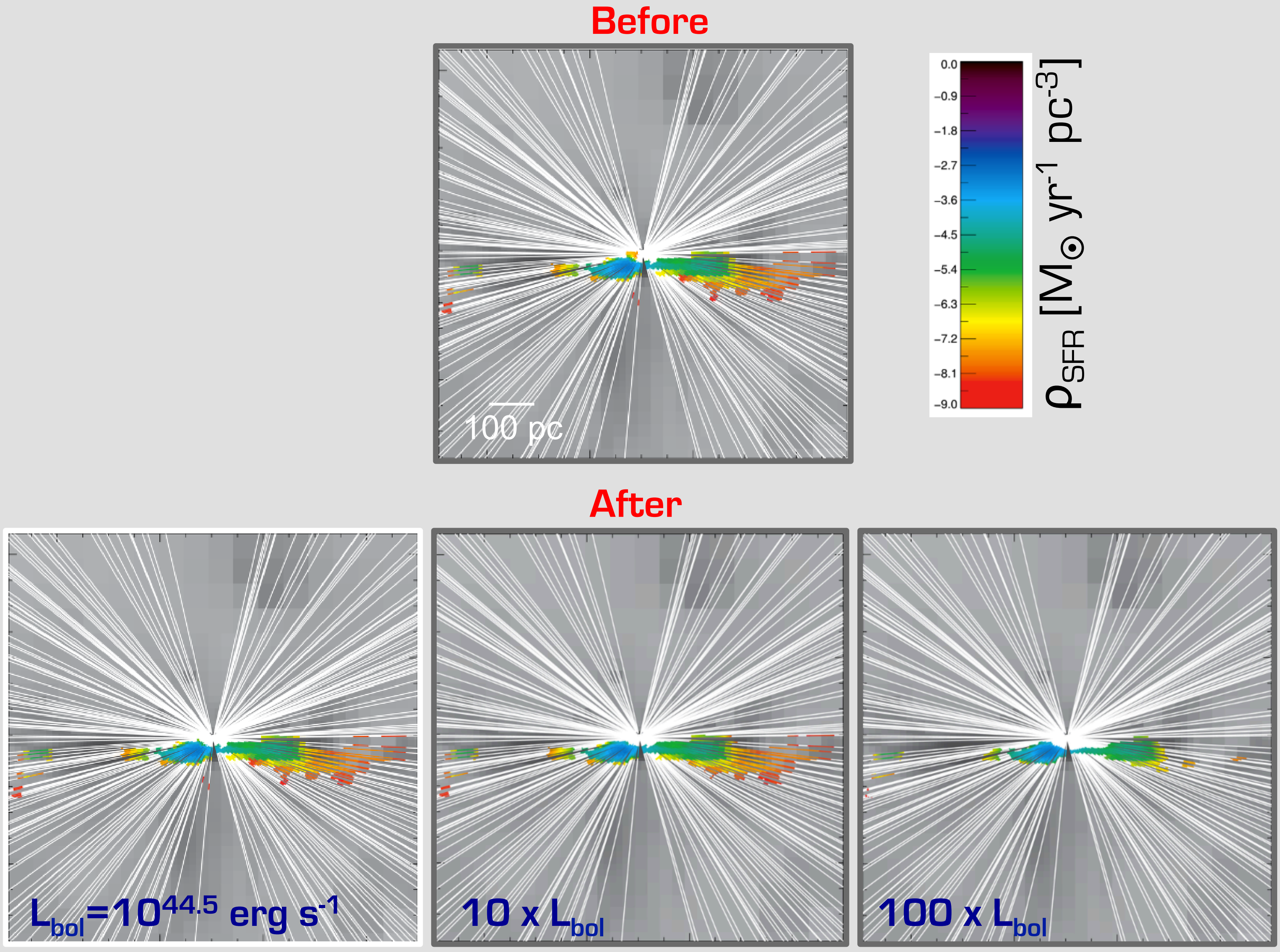


n_H [cm^{-3}] ρ_{SFR} [$M_\odot$ yr^{-1} pc^{-3}]





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



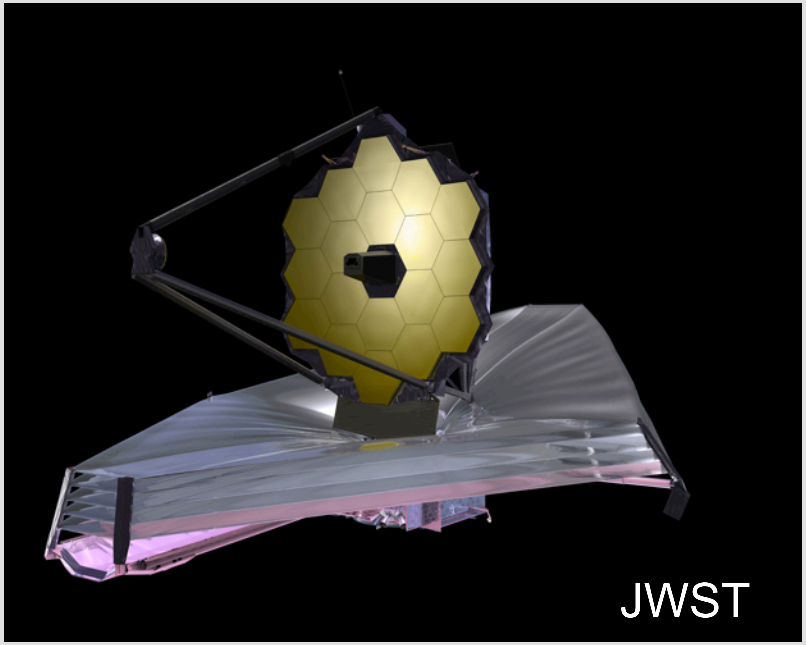
Before
After
0.0
−0.9
−1.8
−2.7
−3.6
−4.5
−5.4
−6.3
−7.2
−8.1
−9.0
ρ_{SFR} [$M_\odot$ yr^{-1} pc^{-3}]
100 pc
$L_{bol}=10^{44.5}$ erg s^{-1}
10 x L_{bol}
100 x L_{bol}

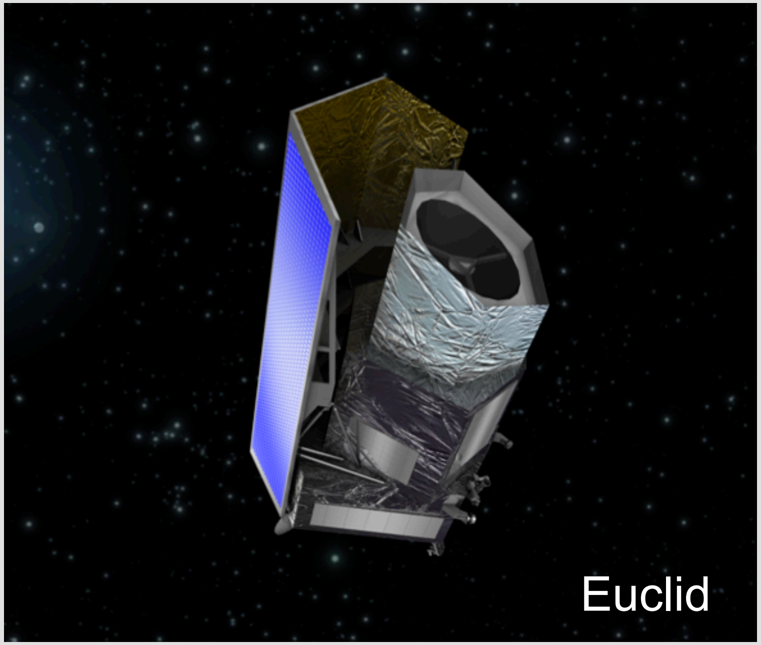
Summary

- AGN identification:
  - MEx diagram (Juneau+11) statistically confirmed *out to z < 1,* but has now been improved to be used to higher redshifts and with less sensitive observations (Juneau+14: arXiv:1403.6832)
- Interstellar gas evolution:
  - Hints that galaxies had different emission-line ratios indicating higher excitation (Brinchmann+08, Liu+08, Shirazi+13, Kewley+13, ...)
- Deep high-redshift emission-line surveys still suffer from systematics due to line flux detection limit
  - → can mimic/exagerate evolutionary effects on AGN diagnostics (Juneau+ submitted)
  - can be taken into account in MEx (& other) diagnostic diagrams
- Clumpy/unstable disks are efficient at fueling BHs; On the opposite, AGN have only negligible (instantaneous) impact on SF

The Future

- Closer comparisons between low and high redshifts
  - although low-z analogs seem to exist, are they just rare populations of more common galaxies in the past?
  - Prepare statistical tools for data mining large datasets





The Future

- Internal physics within galaxies [gas dynamics and ionization from emission lines, 3d spectroscopy (e.g., MUSE & KMOS)]