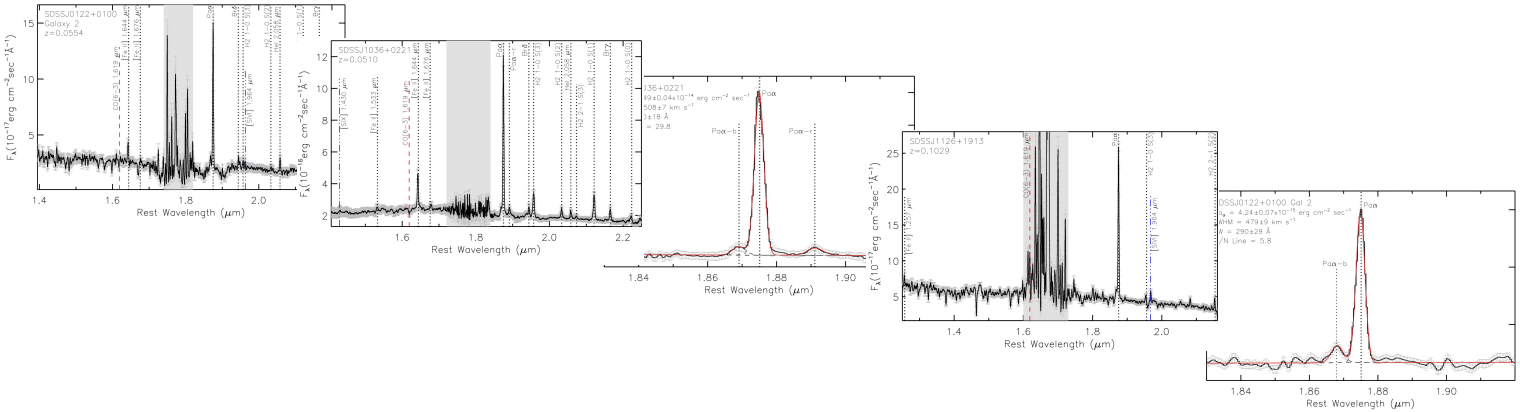
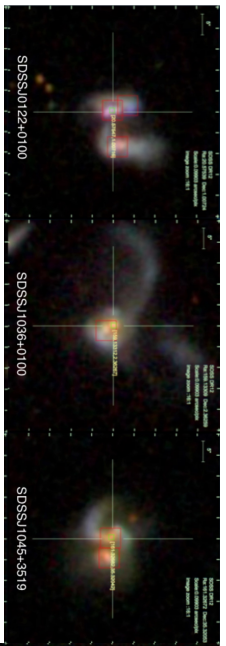


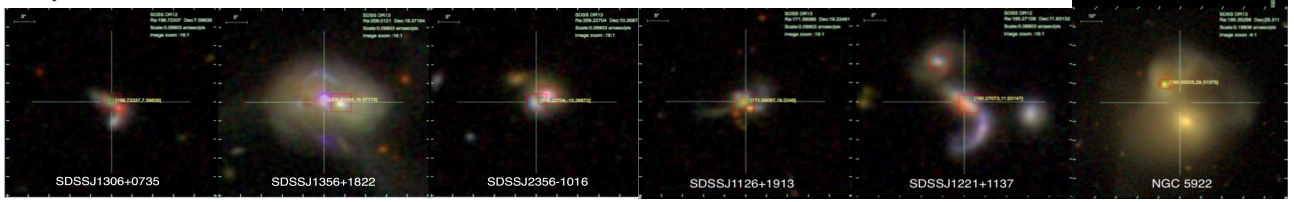
Near-IR and Radio Explorations of Obscured AGNs in Advanced Mergers

- ✓ *Identify traits that betray the AGN excitation and feedback*
- ✓ *Quantify the incidence of (obscured) AGNs triggered by interactions*

Anca Constantin (JMU)

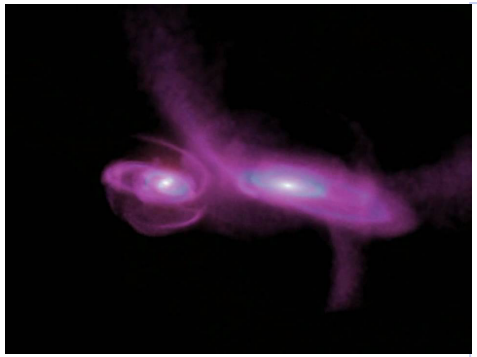
Shobita Satyapal (GMU), Barry Rothberg (LBTO), Krisztina Gabanyi (MTA-ELTE), **Ryan Pfeifle** (GMU), Sara Ellison (UVictoria), Laura Blecha (UFlorida), Jason Ferguson (JMU, GMU)



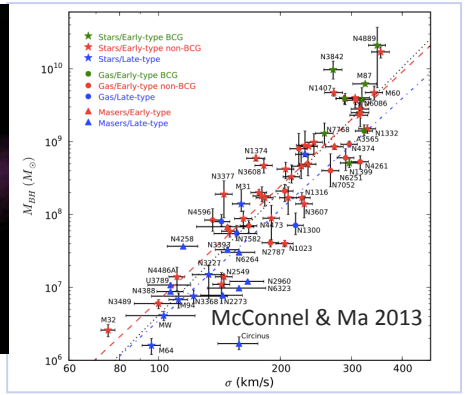


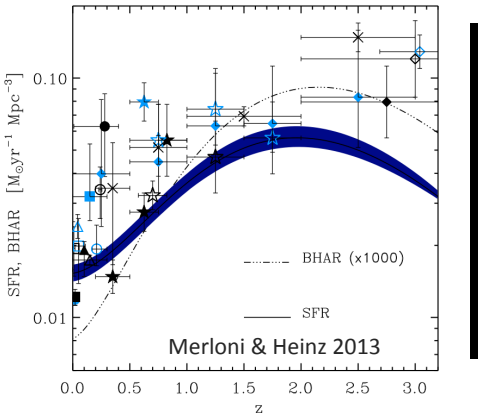
AGNs ⟷ Galaxy mergers

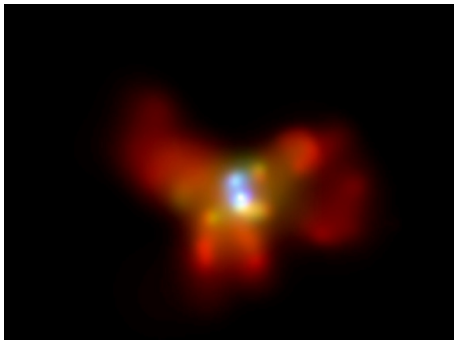
- ΛCDM predicts that interactions are ubiquitous
- Theory predicts gas is funneled towards center
- Can give rise to M-σ relation
- Can explain similarity in cosmic evolution of SFR and BH growth
- AGN Feedback can quench star formation



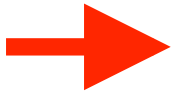
e.g., Di Matteo, Springel, & Hernquist (2005)







Komossa et al. 2003

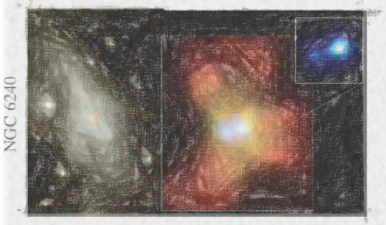


Causal Connection?

(c) Interaction/"Merger"

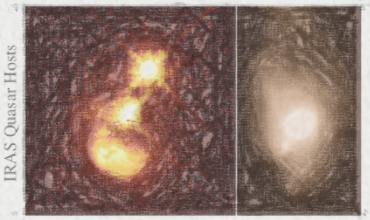
- now within one halo, galaxies interact & lose angular momentum
- SFR starts to increase
- stellar winds dominate feedback
- rarely excite QSOs (only special orbits)

(d) Coalescence/(U)LIRG



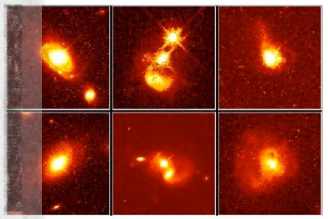
- galaxies coalesce: violent relaxation in core
- gas inflows to center: starburst & buried (X-ray) AGN
- starburst dominates luminosity/feedback, but, total stellar mass formed is small

(e) "Blowout"



- BH grows rapidly: briefly dominates luminosity/feedback
- remaining dust/gas expelled
- get reddened (but not Type II) QSO: recent/ongoing SF in host high Eddington ratios merger signatures still visible

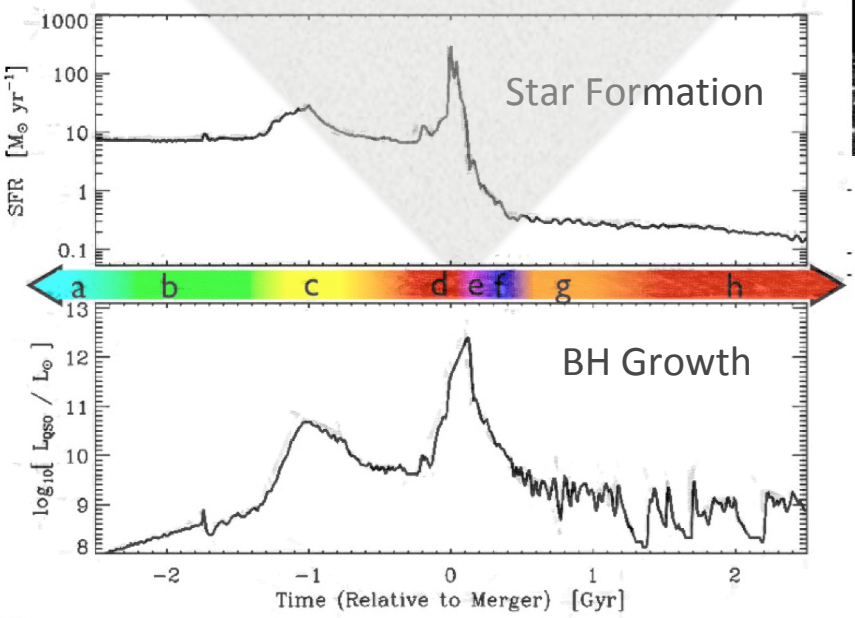
(f) Quasar



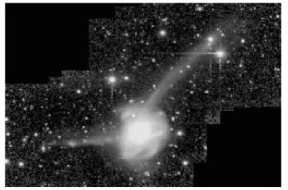
- dust removed: now a "traditional" QSO
- host morphology difficult to observe: tidal features fade rapidly
- characteristically blue/young spheroid

(b) "Small Group"

- halo accretes similar-mass companion(s)
- can occur over a wide mass range
- M_{halo} still similar to before: dynamical friction merges the subhalos efficiently



(g) Decay/K+A

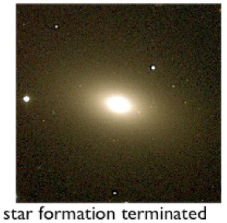


- QSO luminosity fades rapidly
  - tidal features visible only with very deep observations
- remnant reddens rapidly (E+A/K+A)
- "hot halo" from feedback
  - sets up quasi-static cooling

(a) Isolated Disk

- halo & disk grow, most stars formed
- secular growth builds bars & pseudobulges
- "Seyfert" fueling (AGN with M_B>-23)
- cannot redden to the red sequence

(h) "Dead" Elliptical



- star formation terminated
- large BH/spheroid - efficient feedback
- halo grows to "large group" scales: mergers become inefficient
- growth by "dry" mergers

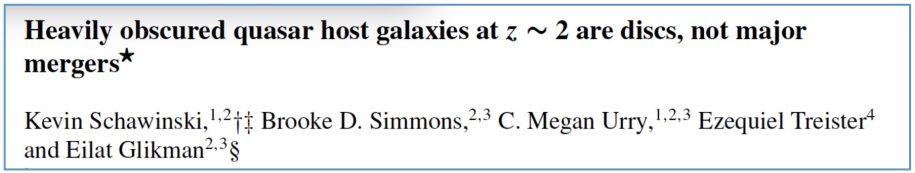
Hopkins et al. (2008);
see also Volonteri et al. (2015)

AGN-Merger Debate

- Dahari et al. 1984
- Keel et al 1985
- Raffanelli et al 1995
- Canalizo & Stockton 2001
- Woods & Geller 2007
- Bennert et al. 2008
- Rogers et al. 2009
- Veilleux et al. 2009
- Koss et al 2010, 2012
- Ramos-Almeida et al. 2011
- Silverman et al. 2011
- Ellison et al. 2011
- Triester et al. 2012
- Shabala et al. 2012
- Sabater et al. 2013
- Satyapal et al. 2014
- Kaviraj et al. 2015
- Kocevski et al. 2015
- Glikman et al. 2015
- Fan et al. 2016
- Ricci et al. 2017
- Goulding et al. 2017
- Donley et al. 2018

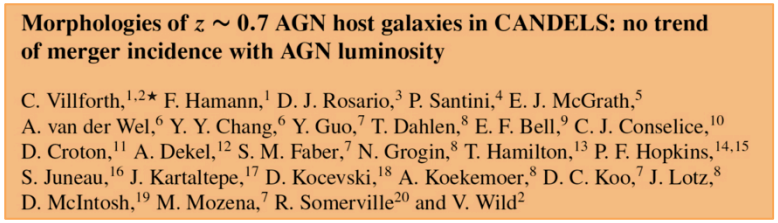
THE BULK OF THE BLACK HOLE GROWTH SINCE $z \sim 1$ OCCURS IN A SECULAR UNIVERSE: NO MAJOR MERGER–AGN CONNECTION*

Mauricio Cisternas[1,20], Knud Jahnke[1], Katherine J. Inskip[1], Jeyhan Kartaltepe[2], Anton M. Koekemoer[3], Thorsten Lisker[4], Aday R. Robaina[1,5], Marco Scodeggio[6], Kartik Sheth[7,8], Jonathan R. Trump[9], René Andrae[1], Takamitsu Miyaji[10,11], Elisabeta Lusso[12], Marcella Brusa[13], Peter Capak[7], Nico Cappelluti[13], Francesca Civano[14], Olivier Ilbert[15], Chris D. Impey[9], Alexie Leauthaud[16], Simon J. Lilly[17], Mara Salvato[18], Nick Z. Scoville[7], and Yoshi Taniguchi[19]



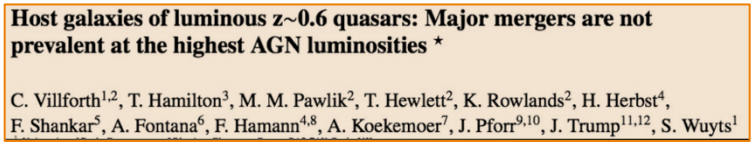
Heavily obscured quasar host galaxies at $z \sim 2$ are discs, not major mergers★

Kevin Schawinski,[1,2]†‡ Brooke D. Simmons,[2,3] C. Megan Urry,[1,2,3] Ezequiel Treister[4] and Eilat Glikman[2,3]§



Morphologies of $z \sim 0.7$ AGN host galaxies in CANDELS: no trend of merger incidence with AGN luminosity

C. Villforth,[1,2]★ F. Hamann,[1] D. J. Rosario,[3] P. Santini,[4] E. J. McGrath,[5] A. van der Wel,[6] Y. Y. Chang,[6] Y. Guo,[7] T. Dahlen,[8] E. F. Bell,[9] C. J. Conselice,[10] D. Croton,[11] A. Dekel,[12] S. M. Faber,[7] N. Grogin,[8] T. Hamilton,[13] P. F. Hopkins,[14,15] S. Juneau,[16] J. Kartaltepe,[17] D. Kocevski,[18] A. Koekemoer,[8] D. C. Koo,[7] J. Lotz,[8] D. McIntosh,[19] M. Mozena,[7] R. Somerville[20] and V. Wild[2]

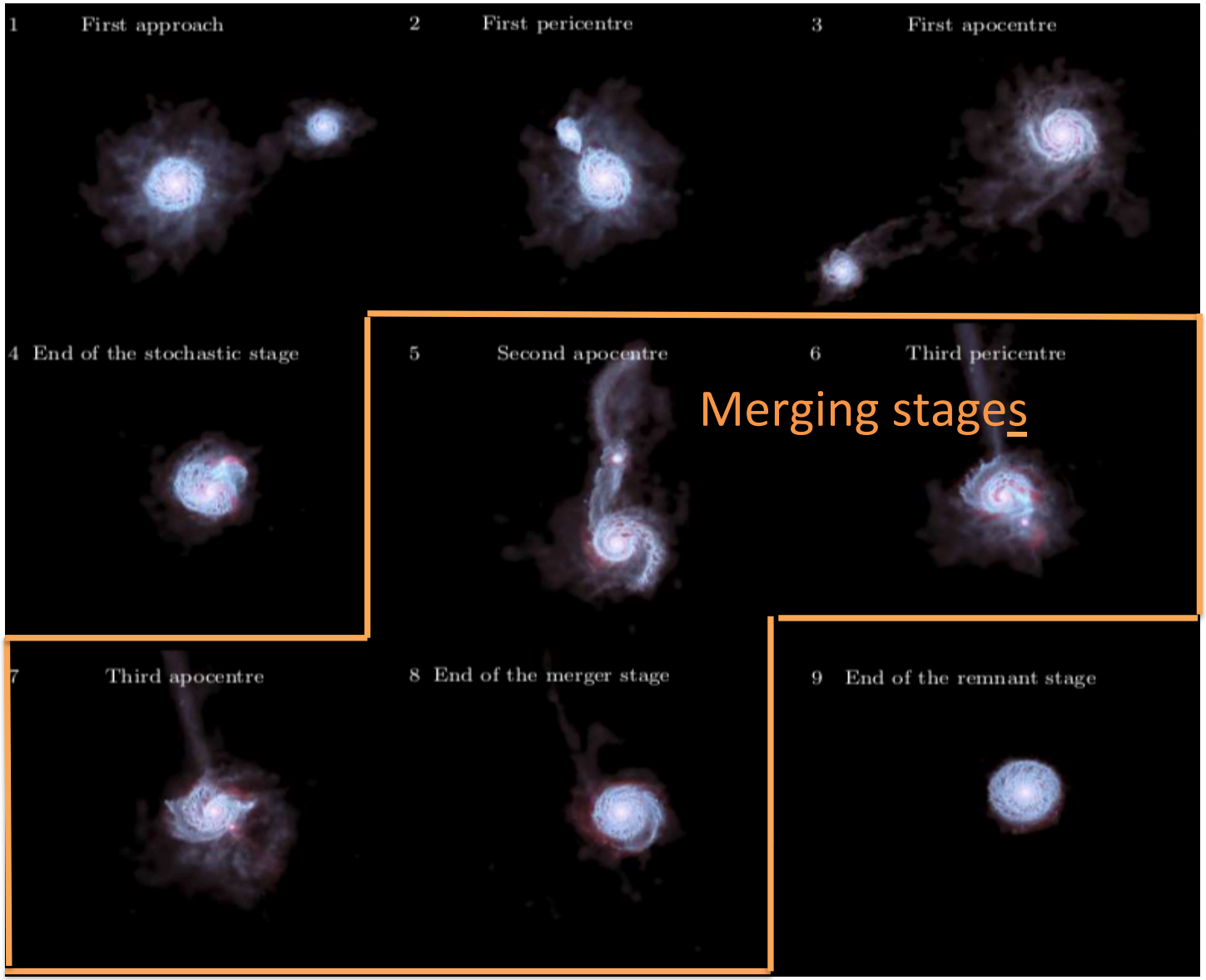


Host galaxies of luminous z~0.6 quasars: Major mergers are not prevalent at the highest AGN luminosities ⋆

C. Villforth[1,2], T. Hamilton[3], M. M. Pawlik[2], T. Hewlett[2], K. Rowlands[2], H. Herbst[4], F. Shankar[5], A. Fontana[6], F. Hamann[4,8], A. Koekemoer[7], J. Pforr[9,10], J. Trump[11,12], S. Wuyts[1]

- Schmitt 2001
- Dunlop et al. 2003
- Grogin et al 2005
- Coldwell & Lambas 2006
- Pierce et al. 2007
- Li et al. 2006, 2008
- Ellison et al. 2008
- Darg et al. 2009
- Gabor et al 2009
- Reichard et al. 2009
- Cisternas et al 2011
- Boehm et al. 2012
- Kocevski et al 2011,2012
- Simmons et al. 2012
- Villforth et al. 2014,2017
- Schawinski et al. 2011
- Kocevski et al. 2012
- Fan et al. 2014
- Rosario et al. 2015
- Bruce et al. 2016
- Mechtley et al. 2016
- Hewlett et al. 2017

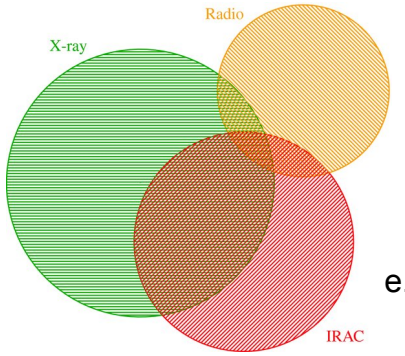
and many more…



Volonteri+ 15

Challenges

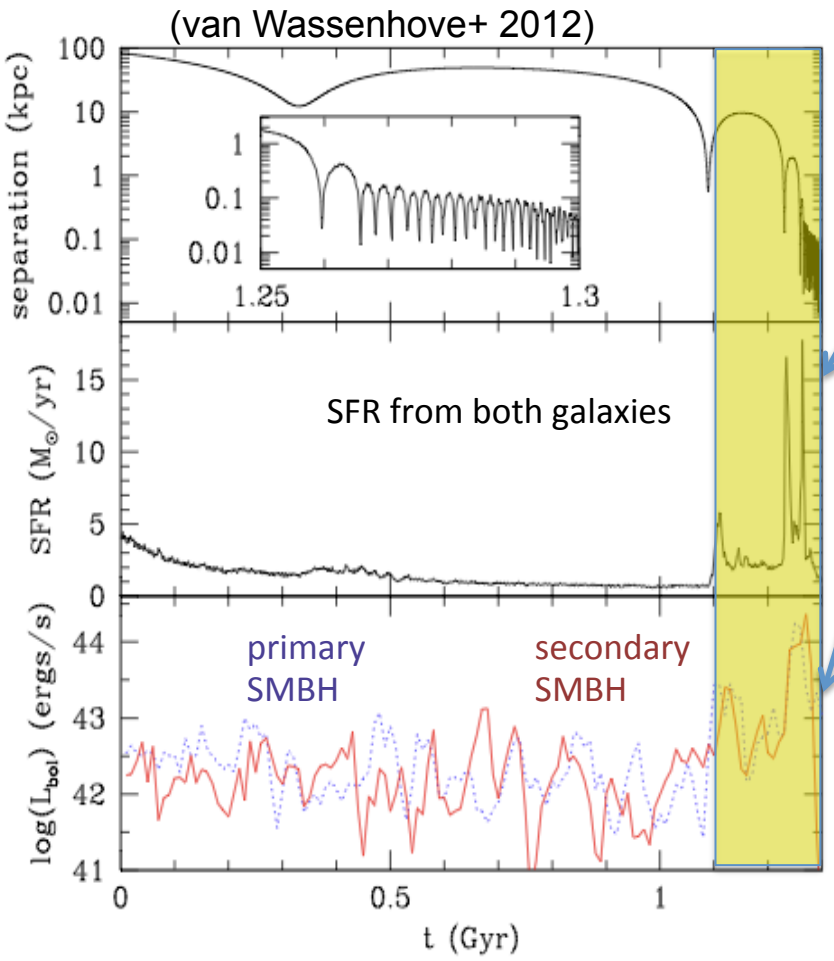
- AGN identification
- Sample size
- Control samples
- Method of morphological classification
- Surface brightness dimming − tidal tails may not be seen
- High SFR masking AGN signatures
- AGN/host contrast ratio in Type 1 AGNs
- Merger stage (e.g., Volonteri+ 15, Capelo+ 17)
- Time delay between AGN ignition and merger signs
- Different AGN fueling processes at play (at low and high L_{bol})



Multiwavelength diagnostics don't always pick out the same AGNs!

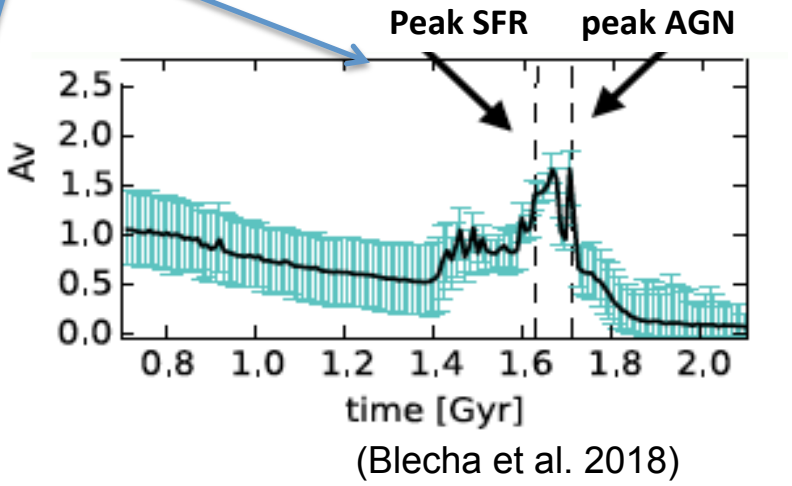
e.g., Hickox et al. 2009

Peak BH growth occurs at small pair separations and is likely obscured



At D<10kpc

- strong SFR +
- Efficient Dual SMBH accretion
- High extinction values



(Blecha et al. 2018)

→ Dual AGNs may be optically obscured the majority of the time when they are active

→ complicate detection of the AGN

also Volonteri+ 2015; Capelo+ 2017

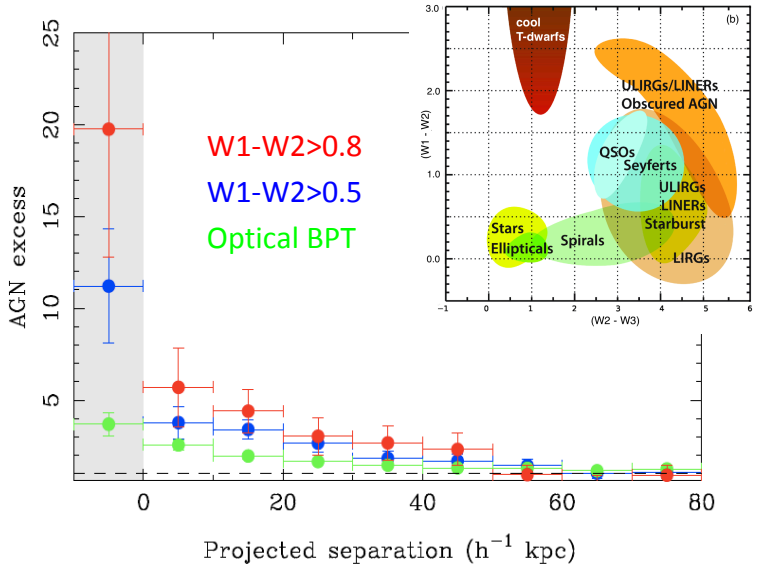
The sample: the brightest advanced mergers pre-selected by WISE

Sample Selection:

- Drawn from Galaxy Zoo (~667,000 galaxies)
- Required high probability of merger (70%; ~1,500)
- keep only separations < 10kpc
- Required WISE W1-W2>0.5 (86 candidates)
- Obtained follow-up Chandra (cycles 15 and 17; PI: Satyapal) observations of the **15 brightest candidates**

(redshift: 0.02 – 0.1; 1” = 0.7 – 2 kpc)

=> 25 detections in 0.3 – 8.0 keV

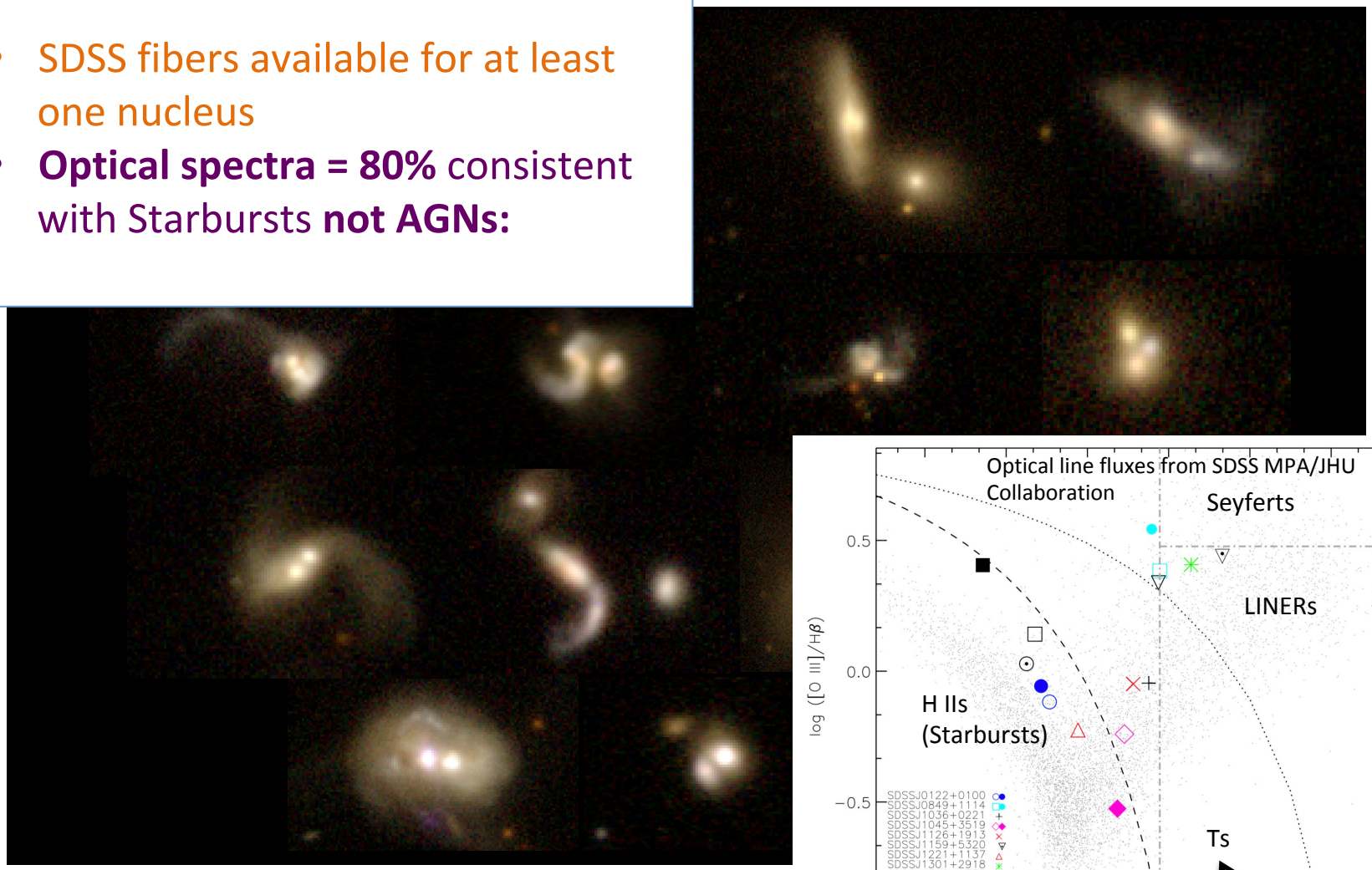


Satyapal et al. (2014)

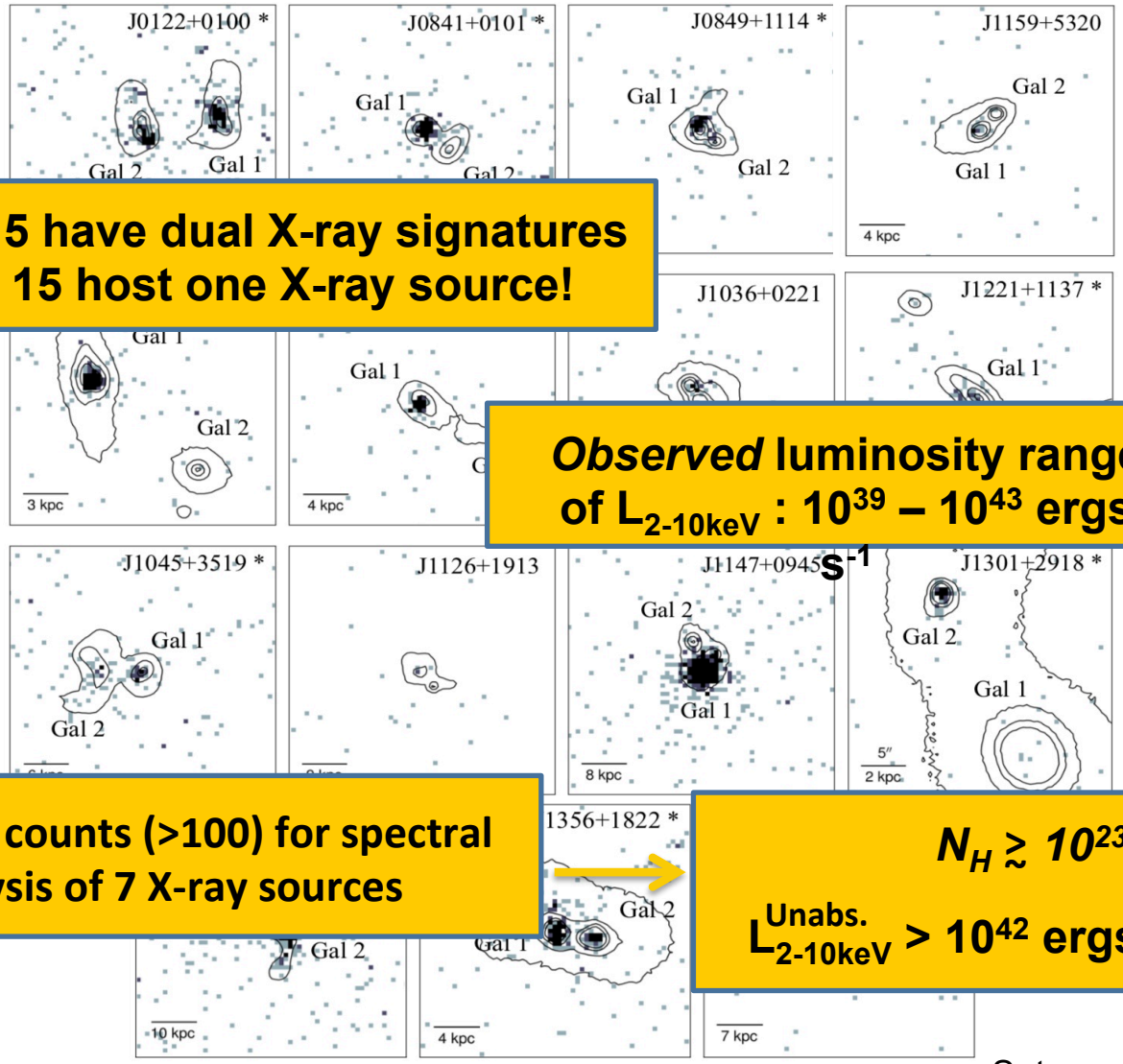
Merger triggered AGNs: detected as red WISE objects, and not seen as AGNs in optical.

The IR–Selected Advanced Mergers

- SDSS fibers available for at least one nucleus
- **Optical spectra = 80%** consistent with Starbursts **not AGNs:**



The IR−Selected Advanced Mergers: 0.3 − 8 keV detections



8/15 have dual X-ray signatures
All 15 host one X-ray source!

***Observed* luminosity range of $L_{2\text{-}10keV}$: 10^{39} – 10^{43} ergs s^{-1}**

Sufficient counts (>100) for spectral analysis of 7 X-ray sources

$N_H \gtrsim 10^{23}$ cm^{-2}

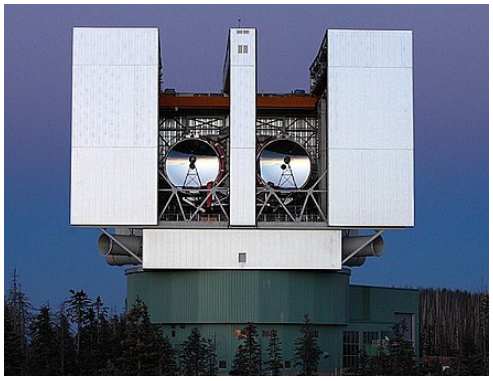
$L^{Unabs.}_{2\text{-}10keV} > 10^{42}$ ergs s^{-1} => AGNs!

Satyapal et al. 2017,
Pfeiflle et al. 2018

How about the rest of the sources…

$L_{2\text{-}10\ keV}$ ≈ comparable to upper limit of most luminous SF galaxies (e.g., Lehmer et al. 2010)

=> X-ray emission from XRBs?



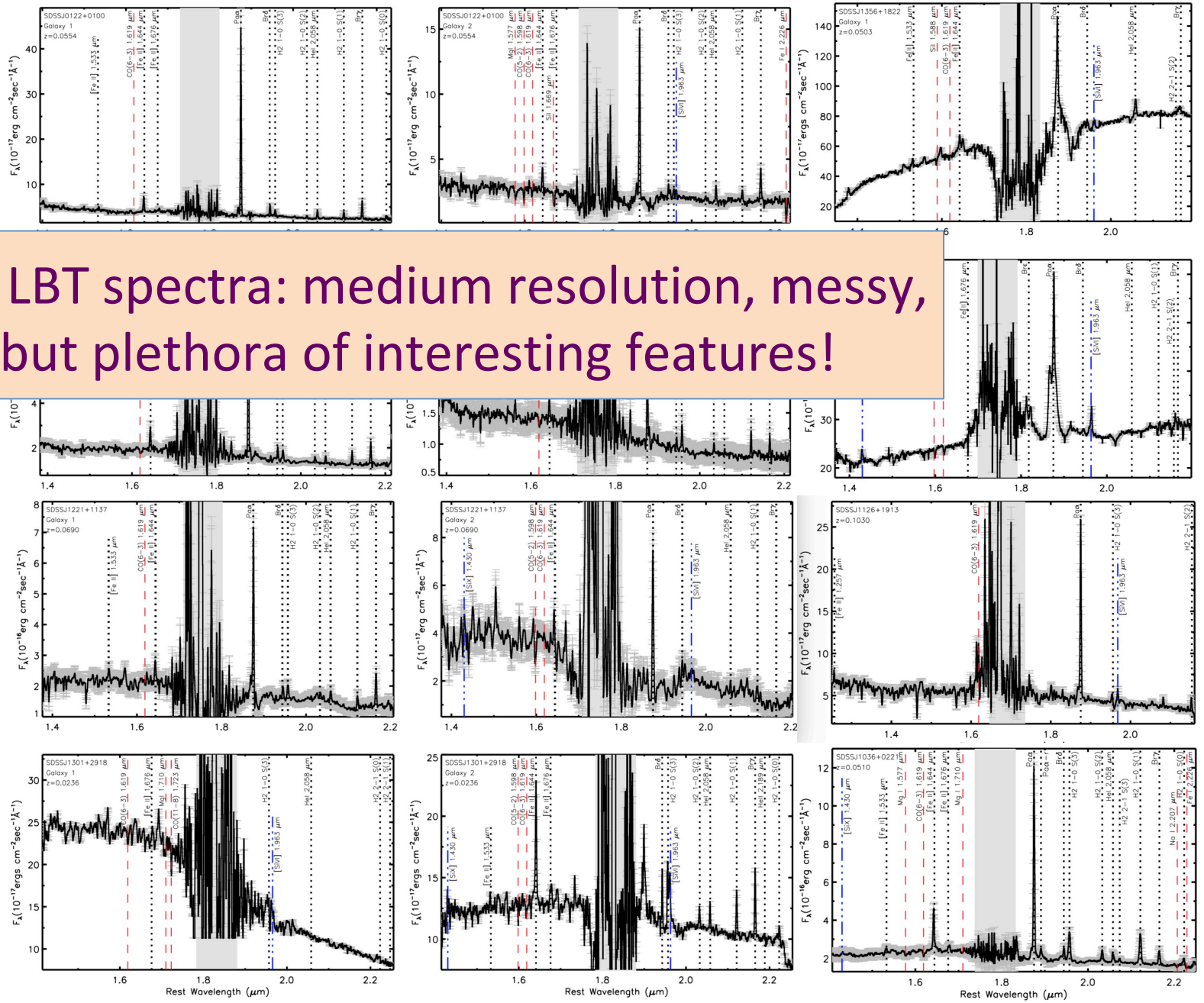
Large Binocular Telescope (LBT):

- Near-IR spectra => extinction-insensitive SFRs → (+ M* (SDSS MPA/JHU) Lehmer et al. 2010) → L_X produced by XRBs
- Assuming Paα flux solely from gas ionized by hot young stars → upper limits of L_X (XRBs)

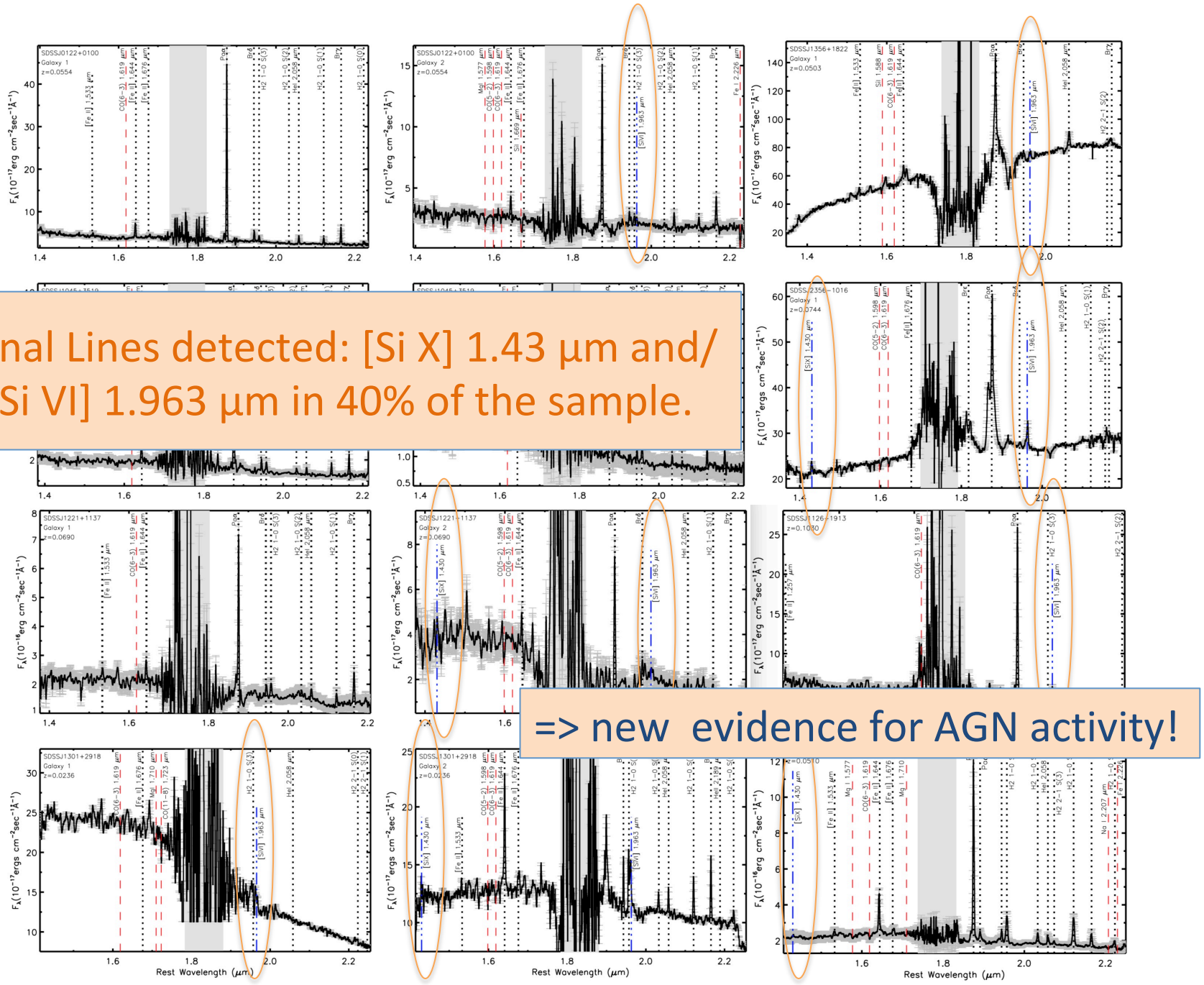
L_X (XRBs) < $L^{observed}_{2\text{-}10\ keV}$ →

XRBs not sufficient to account for observed L_X

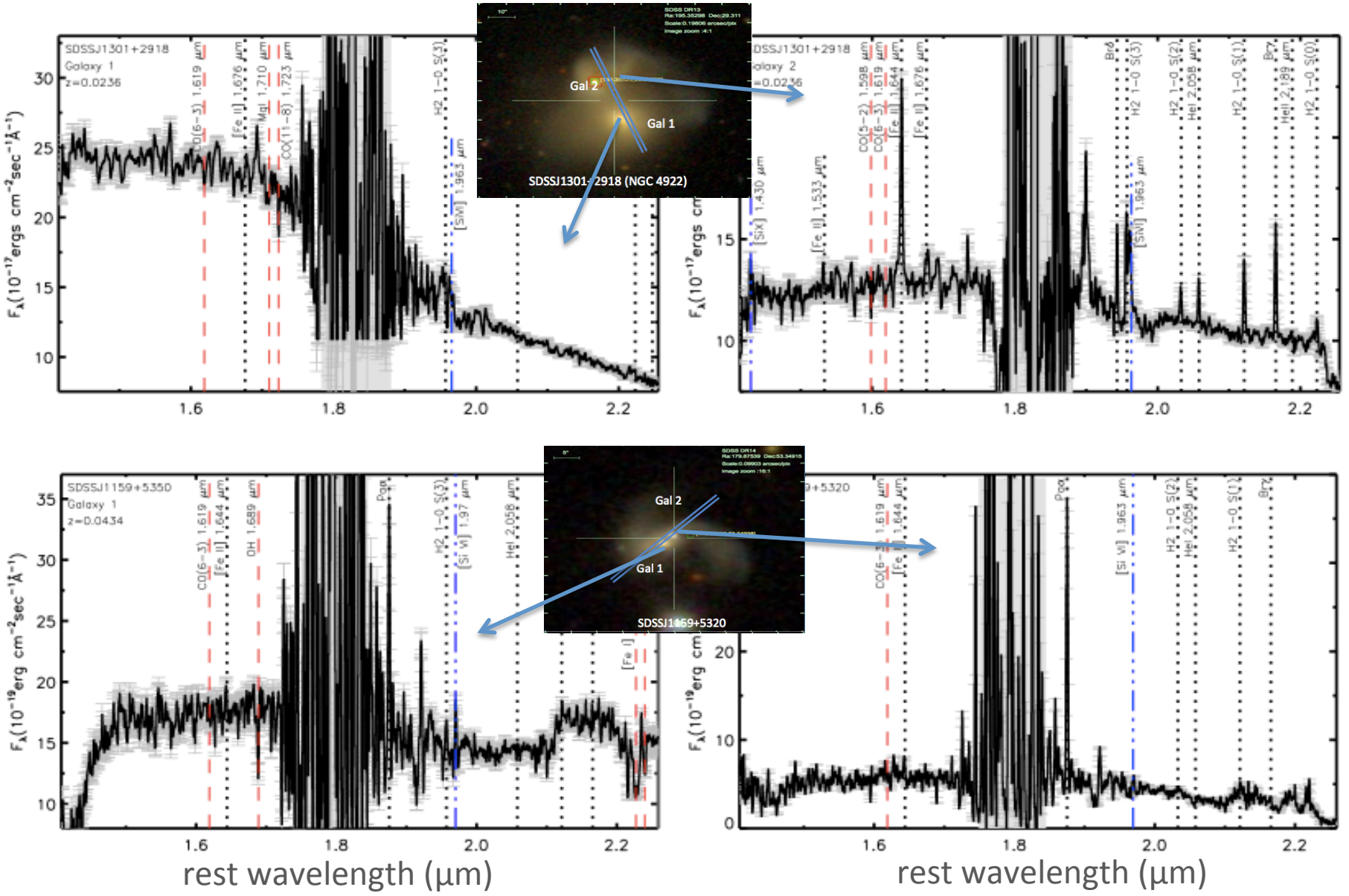
=> Highly suggestive of presence of at least one AGN in <u>all</u> mergers



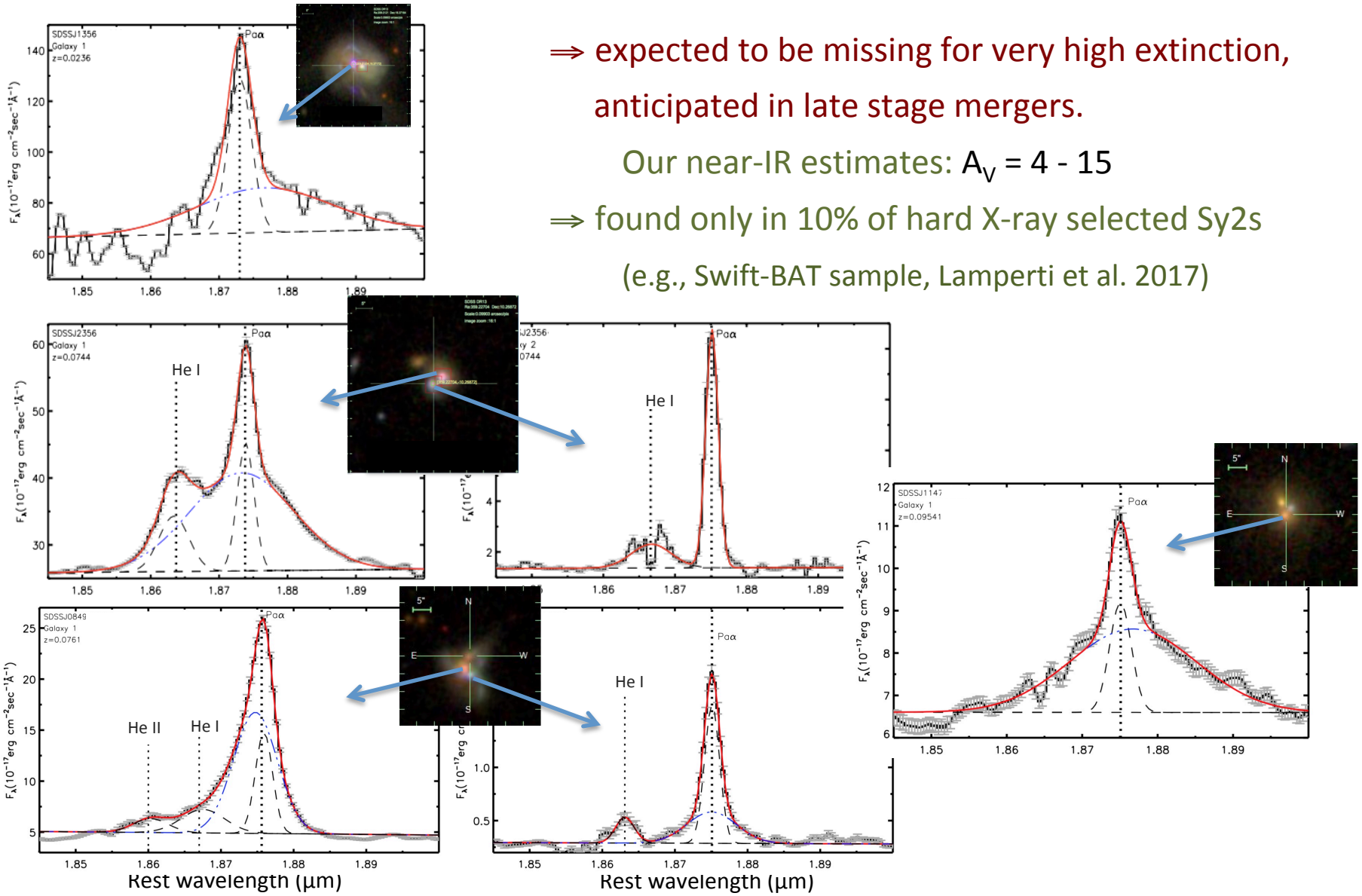
The LBT spectra: medium resolution, messy, but plethora of interesting features!


Coronal Lines detected: [Si X] 1.43 µm and/ or [Si VI] 1.963 µm in 40% of the sample.
=> new evidence for AGN activity!
Rest Wavelength (µm)
Rest Wavelength (µm)
Rest Wavelength (µm)

2 new dual AGN systems!



Broad emission lines (FWHM > 1000 km/s) in 7 galaxies



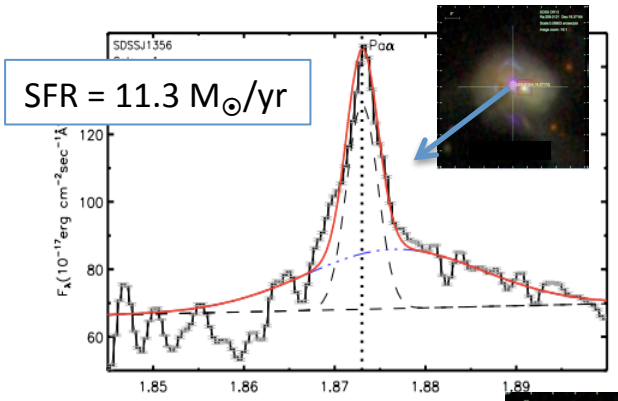
⇒ expected to be missing for very high extinction, anticipated in late stage mergers.

Our near-IR estimates: A_V = 4 - 15

⇒ found only in 10% of hard X-ray selected Sy2s

(e.g., Swift-BAT sample, Lamperti et al. 2017)

Broad emission lines (FWHM > 1000 km/s) in 7 galaxies



SFR = 11.3 $M_\odot$/yr

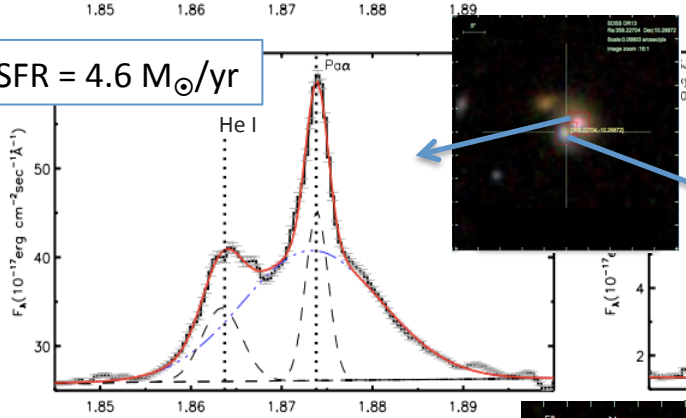
⇒ BLR often shifted by 300 – 800 km/s

⇒ indicative of out/in- flowing gas

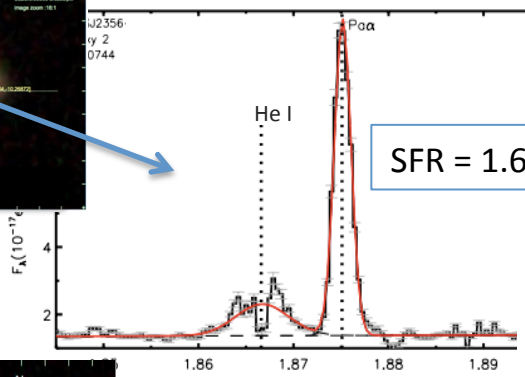
$\dot{M}_{flow}$ ≈ 100s $M_\odot$/yr (as seen in ULIRGs; e.g., Veilleux+ 2005)

$L_{bol} \approx 10 \times L_{2\text{-}10keV} \approx 10^{42} - 10^{44}$ erg/s =>

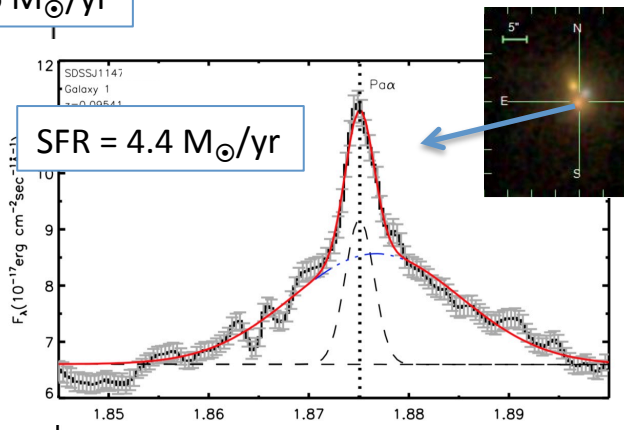
$\dot{M}_{flow} \approx 10^2 - 10^3\ \dot{M}_{acc}$



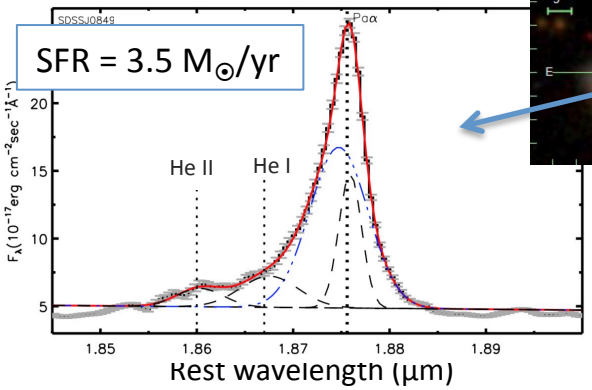
SFR = 4.6 $M_\odot$/yr



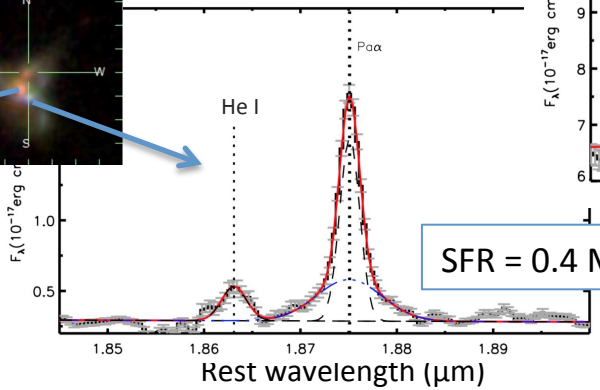
SFR = 1.6 $M_\odot$/yr



SFR = 4.4 $M_\odot$/yr

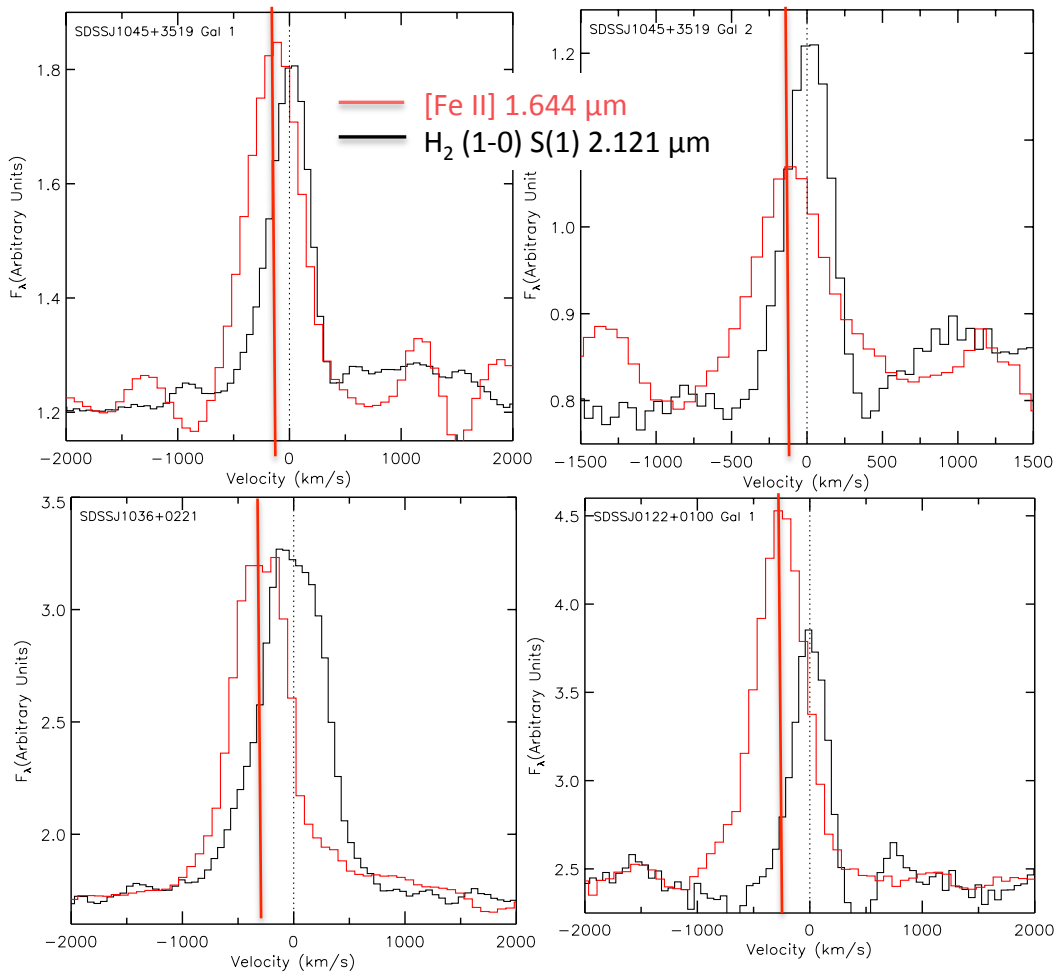


SFR = 3.5 $M_\odot$/yr



SFR = 0.4 $M_\odot$/yr

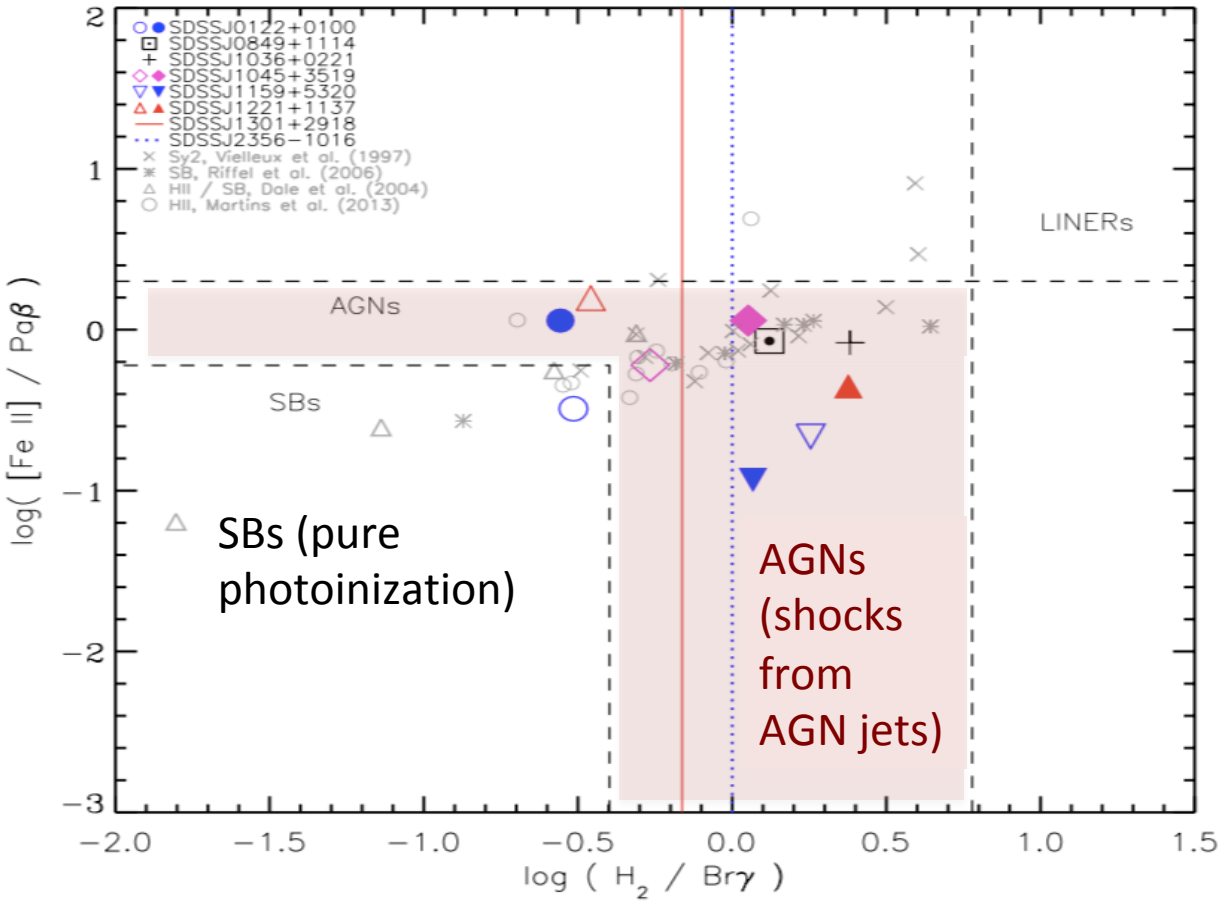
Kinematics of [Fe II] and H_2 also suggestive of gas flows



- [Fe II] blueshifted relative to systemic velocity ($\Delta v \approx 300$ km/s)
- No shift in H2

⇒Evidence for outflows?

Near-IR Line Diagnostic diagrams consistent with AGN ionization in (almost) all cases



[Fe II]/Paβ:

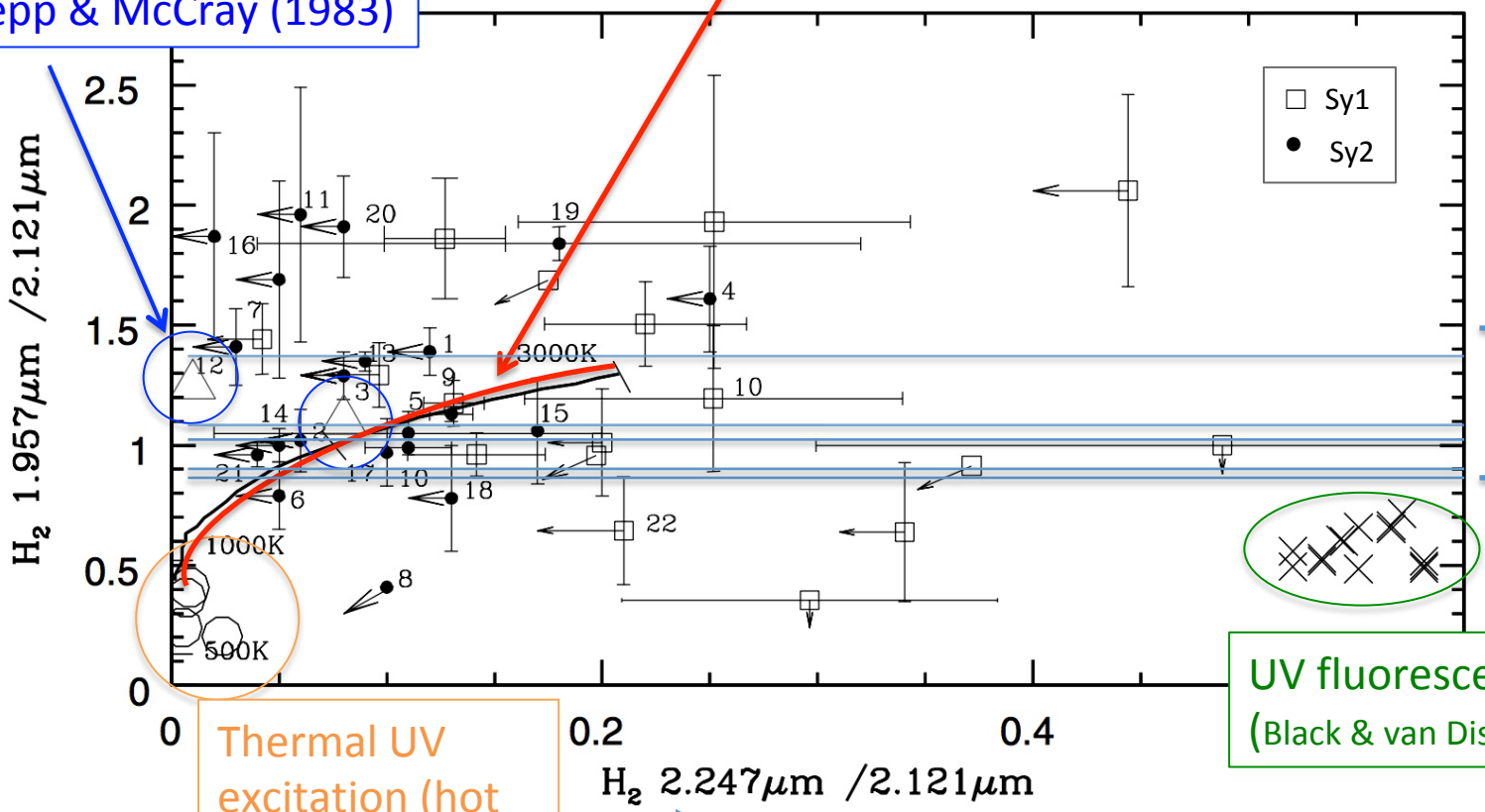
- constrains the amount of [Fe II] produced by SBs vs. AGN jets/shocks.

(e.g., Simpson+1996, Larkin+ 1998, Rodriguez-Ardila+ 2005, Riffel+ 2013)

Near-IR Diagnostic diagrams consistent with AGN ionization in (almost) all cases

X-ray heating
Lepp & McCray (1983)

thermal component between 1000 and 3000 K



Our sample

UV fluorescence
(Black & van Dishoeck 1987)

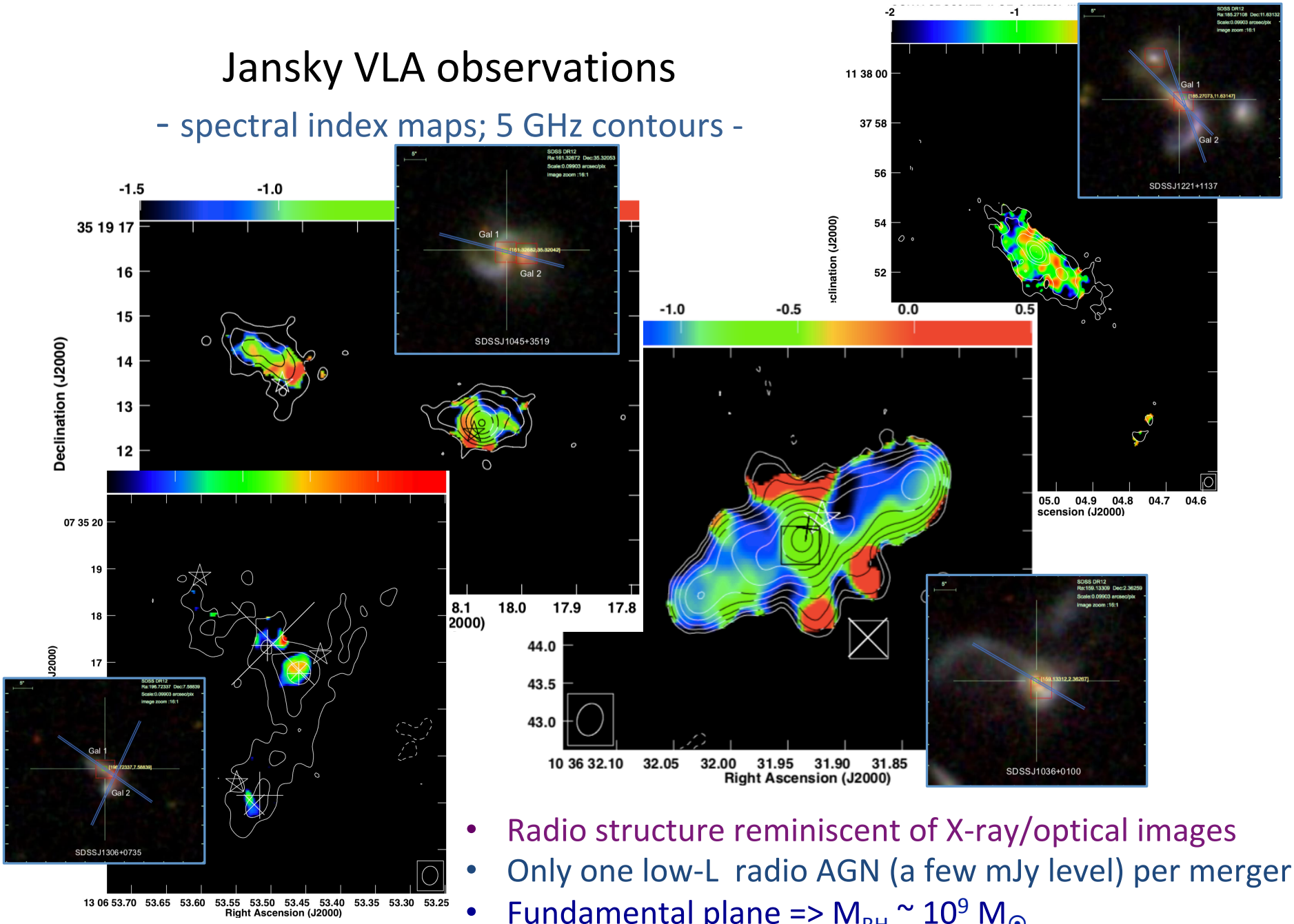
Thermal UV excitation (hot young stars; Sternberg & Dalgarno 1989)

No data; no constraints on x-axis values

(adapted from Rodríguez-Ardila, Riffel & Patoriza 2005)

Jansky VLA observations

- spectral index maps; 5 GHz contours -



- Radio structure reminiscent of X-ray/optical images
- Only one low-L radio AGN (a few mJy level) per merger
- Fundamental plane => $M_{BH} \sim 10^9\ M_\odot$

Summary

- SF and AGN activity peak during the advanced merging phase but highly obscured
- IR selection produced the largest # of dual AGN (candidates) so far
  - *increased the number of confirmed dual AGNs by over 50%*

- X-rays: at least 1 detection in all mergers, with duals (triples) in 8 out of 15 systems
- Near-IR spectroscopy:
  - Evidence of hidden BLR, also possible detection of outflows
  - 40% with coronal lines: at least two secure new AGN pairs
  - Diagnostic diagrams consistent with AGN ionization in all cases*; H_2 excitation most likely produced by AGN*

Satyapal et al. 2017, Pfeiflle et al. 2018, Pfeiflle et al. in prep., Constantin et al. in prep.