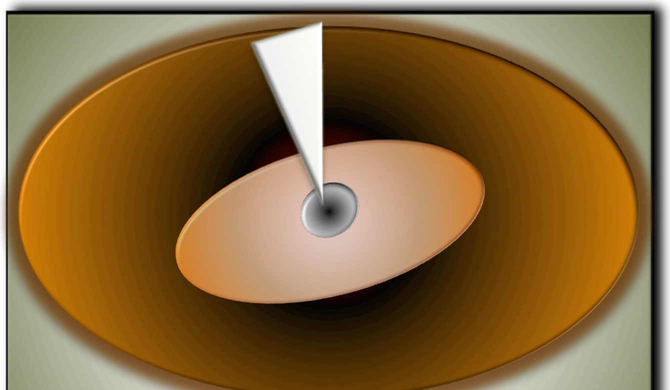
Observational constraints on the impact of luminous AGN on star formation

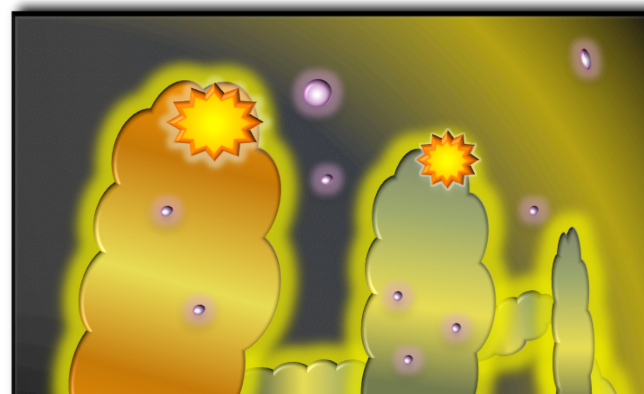
Chris Harrison (Durham)
Flora Stanley, Jim Mullaney (Sheffield), Dave Alexander, Mark Swinbank

AGN versus Star Formation



AGN: BH growth

Observed galaxy/BH properties and relationships



SF: Galaxy growth

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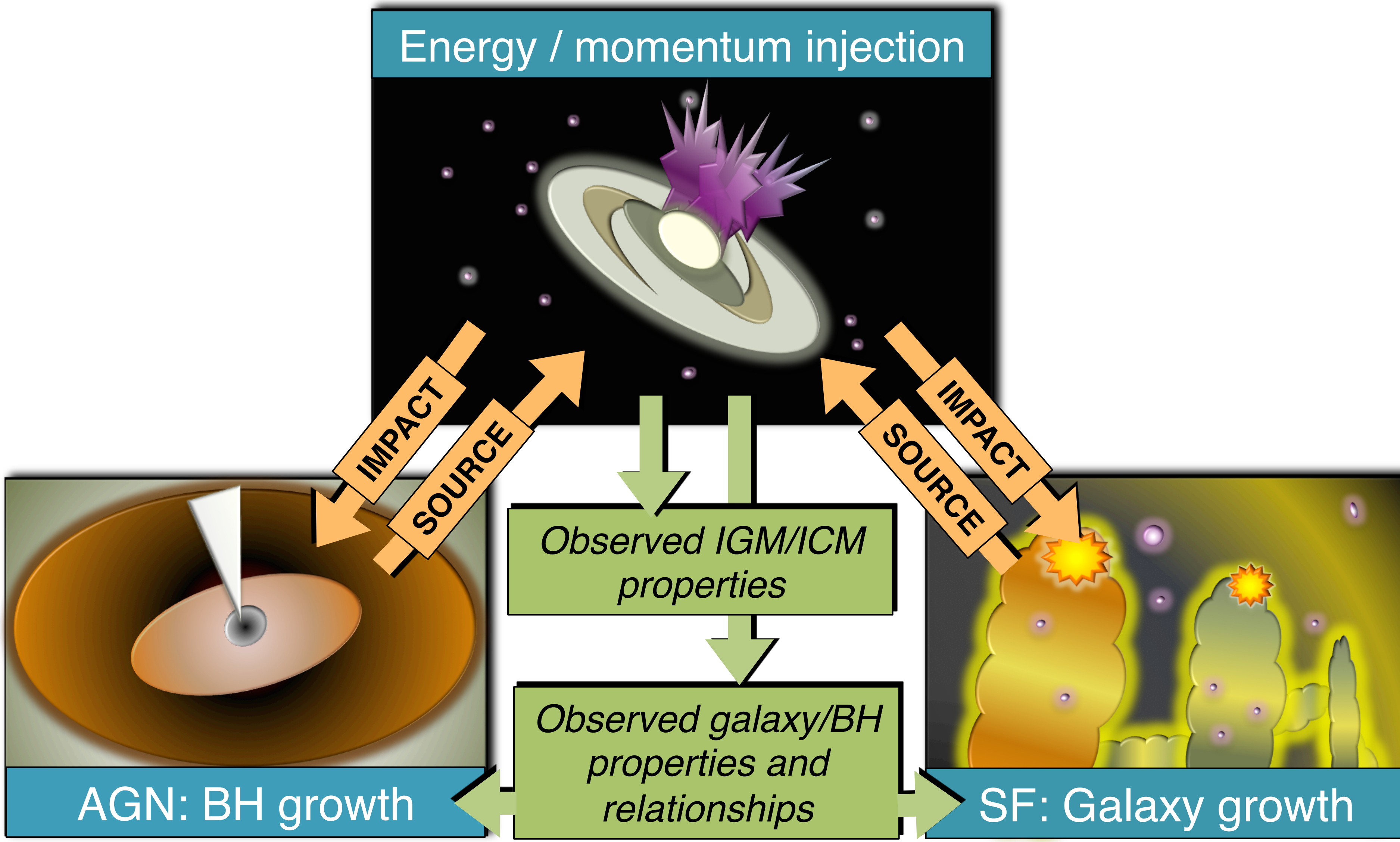
AGN versus Star Formation



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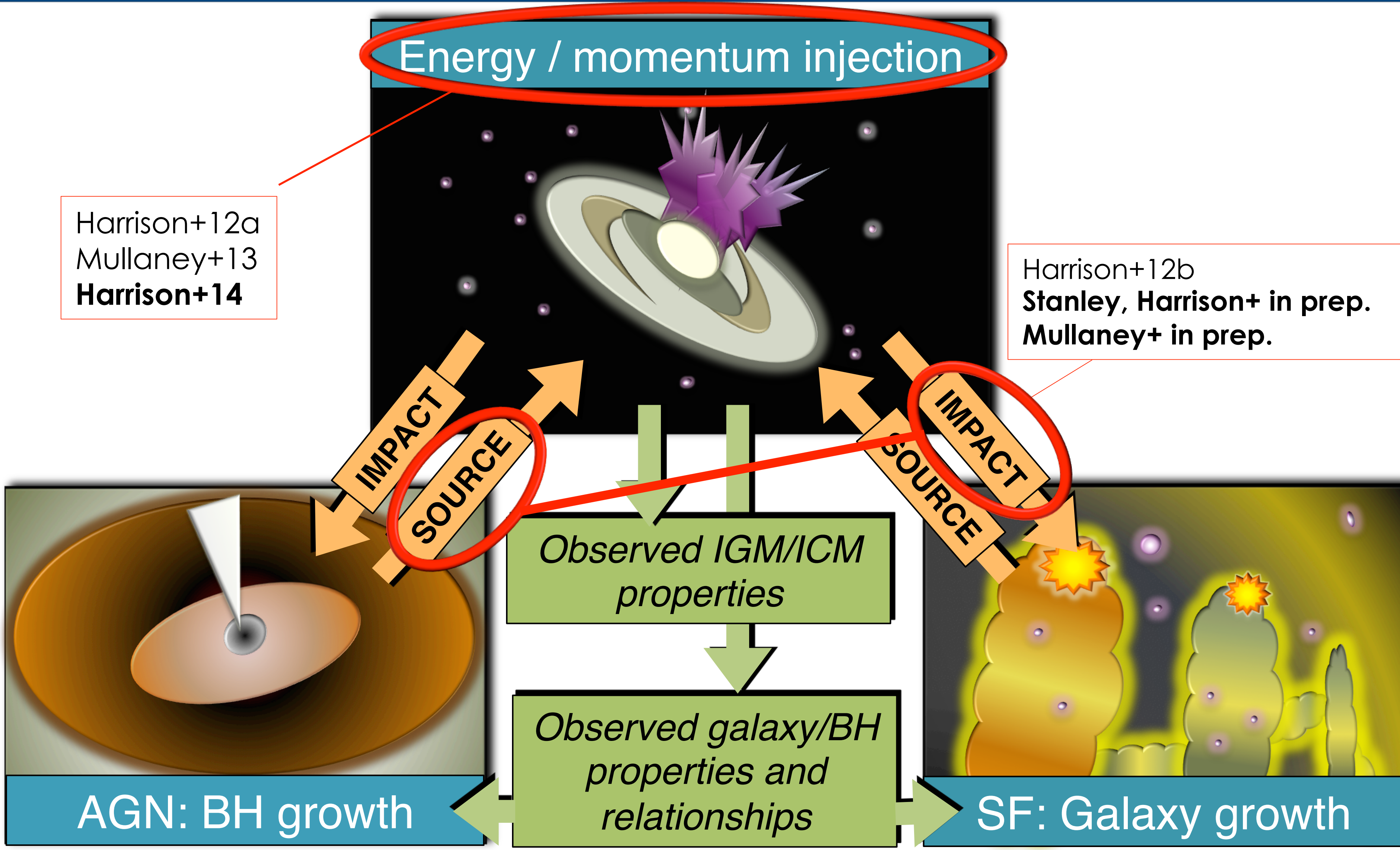
AGN versus Star Formation



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Where do our observations fit in?

Harrison+12a
Mullaney+13
Harrison+14

The Targets

Luminous AGN / quasars:

$L_{[OIII]} > 10^{42}$ erg/s (z~0.1-0.4)

$L_{X} > 10^{42}$ erg/s (z~0.2-3.2)

Harrison+12b
Stanley, Harrison+ in prep.
Mullaney+ in prep.

The Key Questions

1. **What are the properties and prevalence of galaxy-wide ionised outflows?**
   Scales of ~0.5 -10 kpc
2. **What are the SFRs of luminous AGN?**
   Galaxy-integrated SFRs using MIR to submm photometric data

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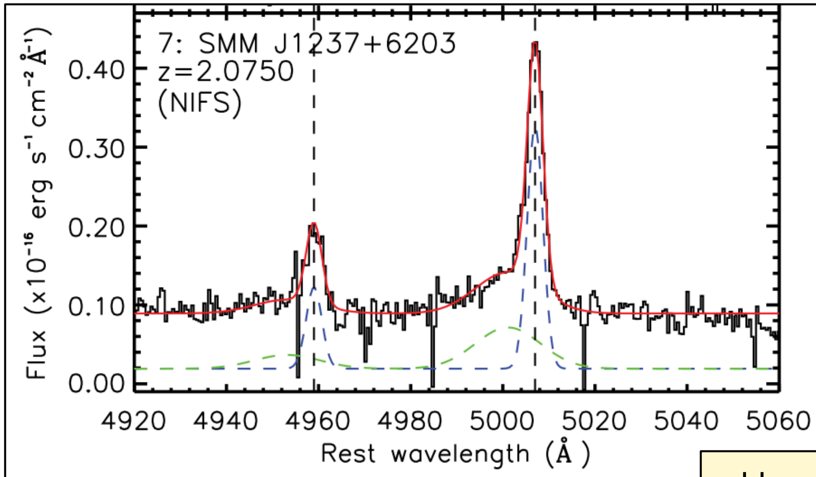
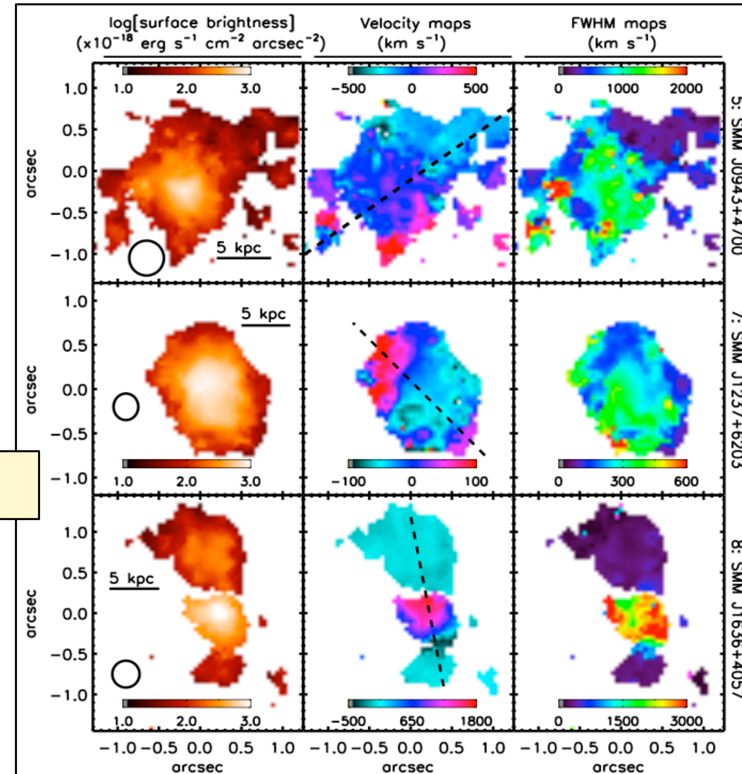
Galaxy-wide ionised outflows found with IFUs



Harrison+12a



- Kiloparsec-scale ionised outflows
- High energies (~ binding energy)
- Implies rapid gas expulsion

Radio-loud AGN

(e.g., Fu & Stockton 09)

HzRGs

(e.g, Nesvadba+06,08)

Radio-quiet AGN

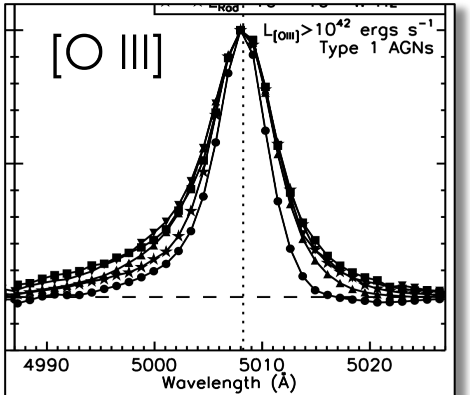
(e.g. Humphrey+10; Greene+11; Liu+13)

ULIRG+AGNs

(e.g, Alexander+10; Harrison+12a; Westmoquette+12; Rodriguez-Zaurin+13; Rupke & Veilleux 13; Arribas+14)

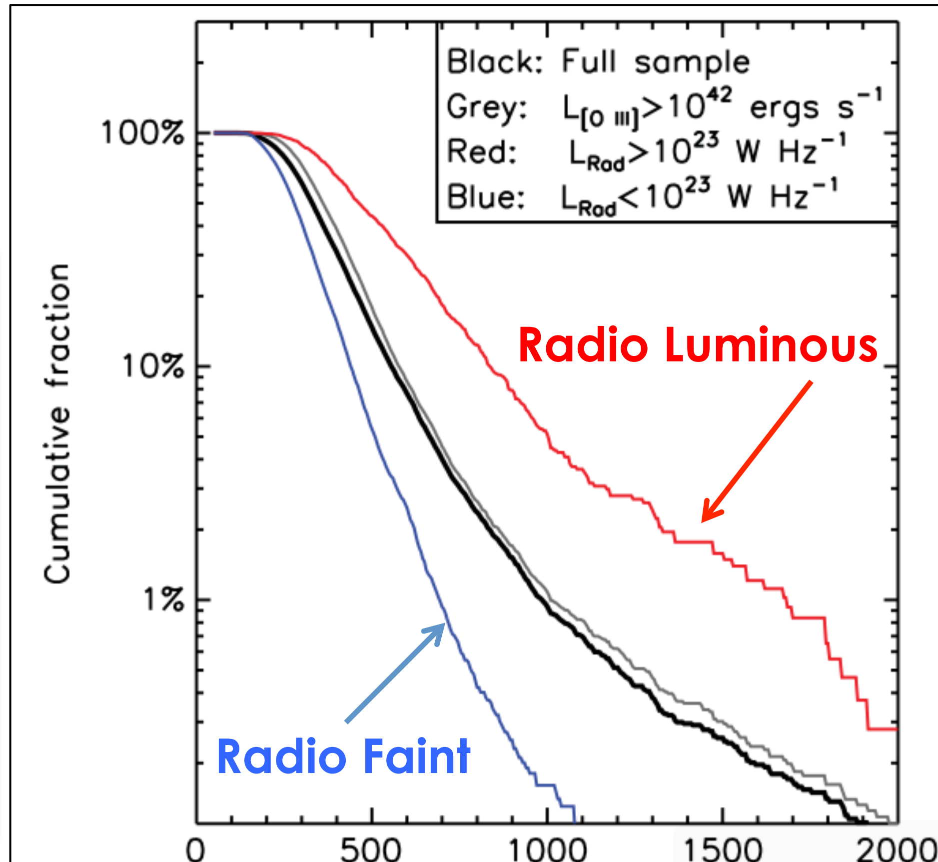
BUT HOW REPRESENTATIVE ARE THESE OBSERVATIONS?

Constraining the parent population: z<0.4 SDSS AGN



Results from fitting emission-line components to 24,000 AGN spectra

- ~20% show $FWHM_{Avg}$ > 500 km s^{-1}
- When $L_{1.4} > 10^{23}$ W Hz^{-1} **five times more likely** to have $FWHM_{Avg}$ > 1000 km s^{-1}
- No clear trends with $L_{[OIII]}$ or Eddington ratio (taking into account intrinsic correlations)



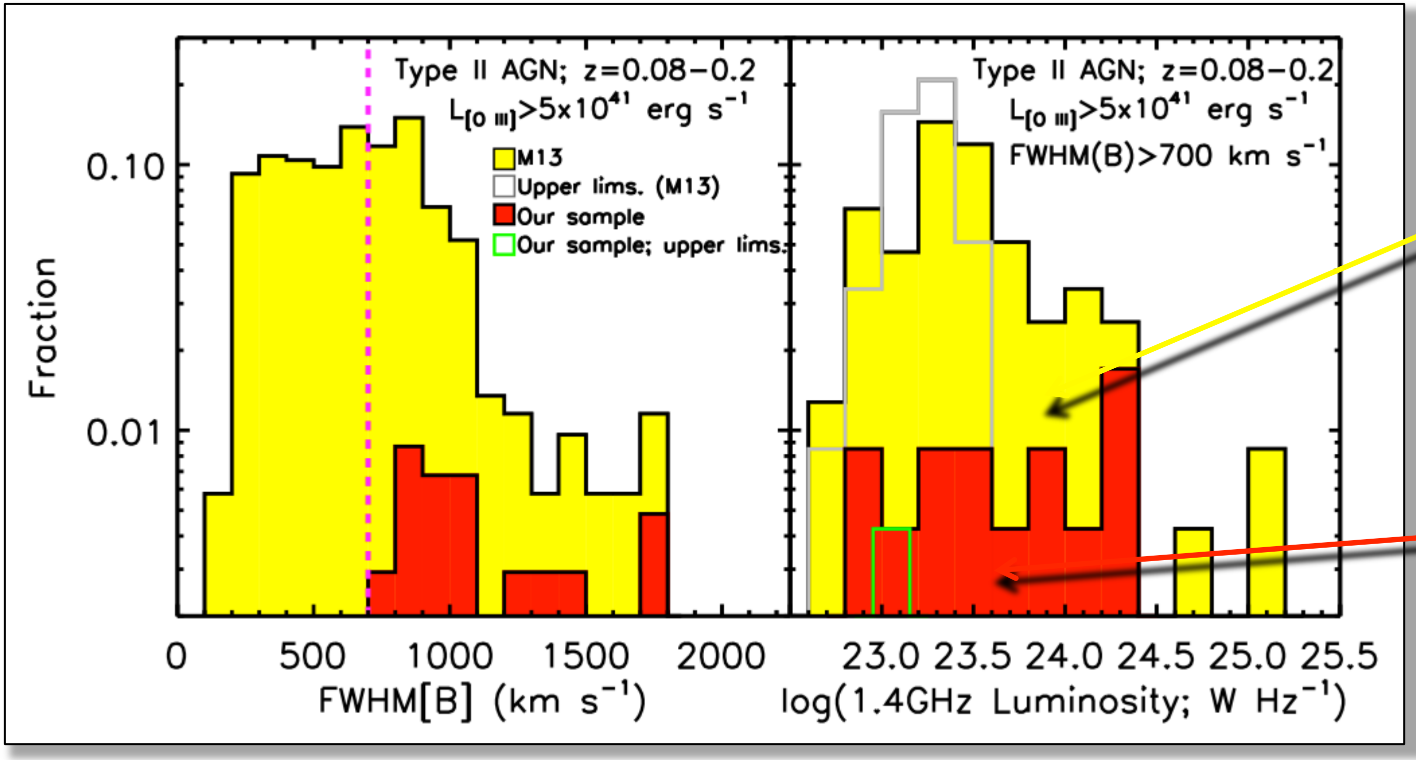
$FWHM_{Avg}$ (km/s) = flux weighted average

Mullaney+13

also see Zakamska & Greene 14

IFU targets from a constrained parent sample

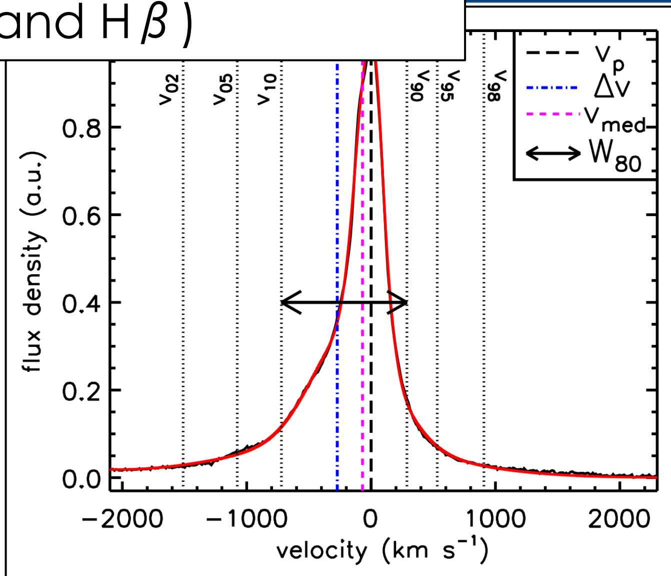
Harrison+14



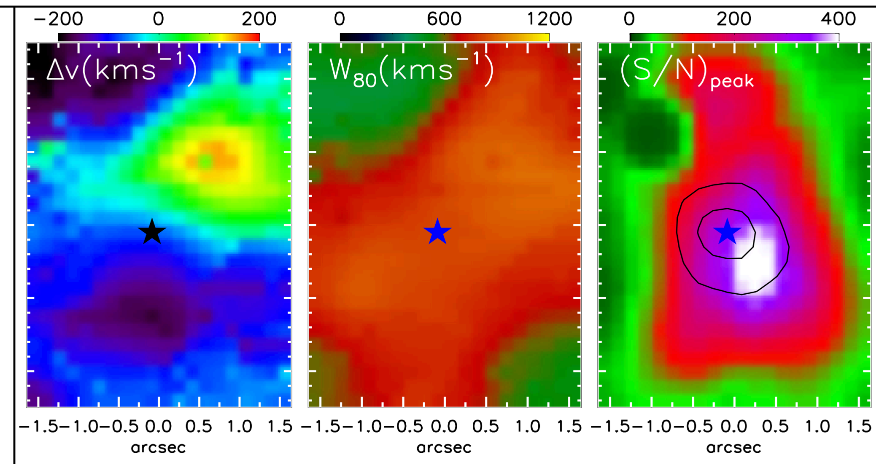
- Select luminous ($L_{[O\ III]}$>~10^{42} erg/s), z<0.2, type 2 AGN
- ~45% have *significant* broad [O III] component (FWHM>700 km/s)
- Select 16 of these for IFU follow-up on Gemini-GMOS
- Can place observations into the context of the overall population

The Data: One Example

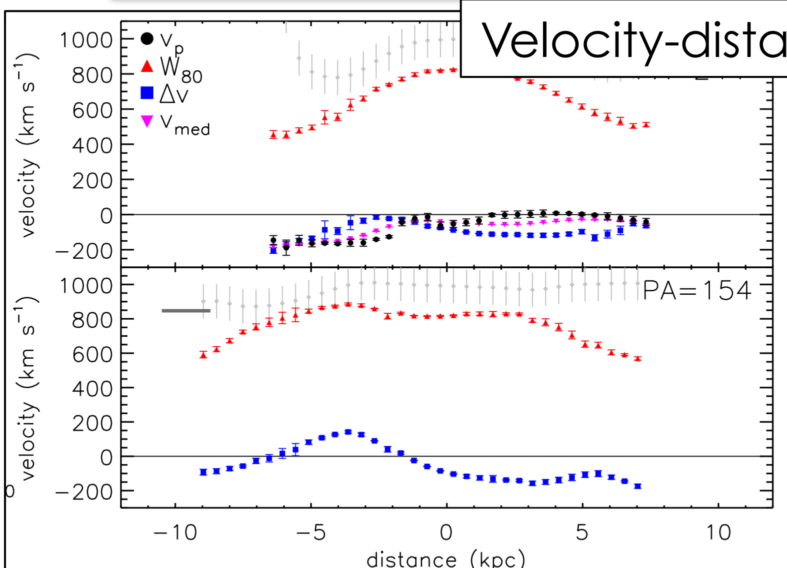
Non-parametric velocities ([O III] and Hβ)



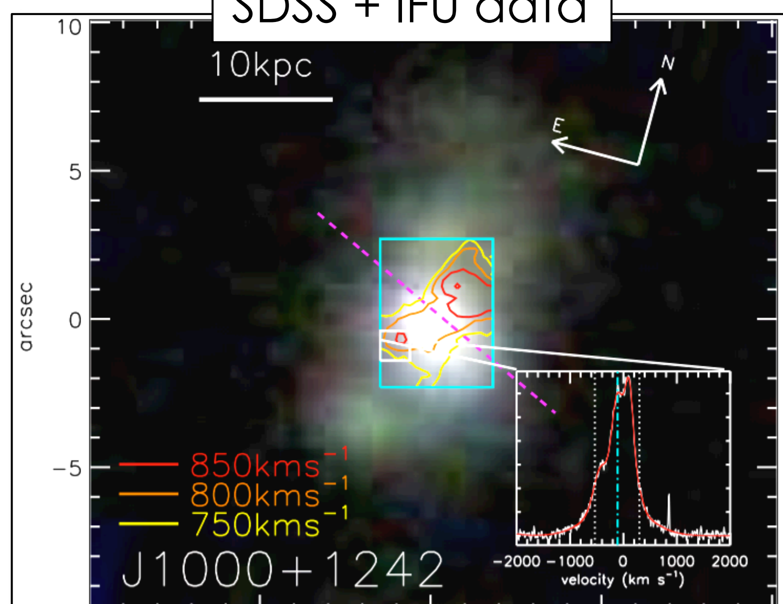
Velocity offset | Line-width | [O III] Sur. Br.



Velocity-distance

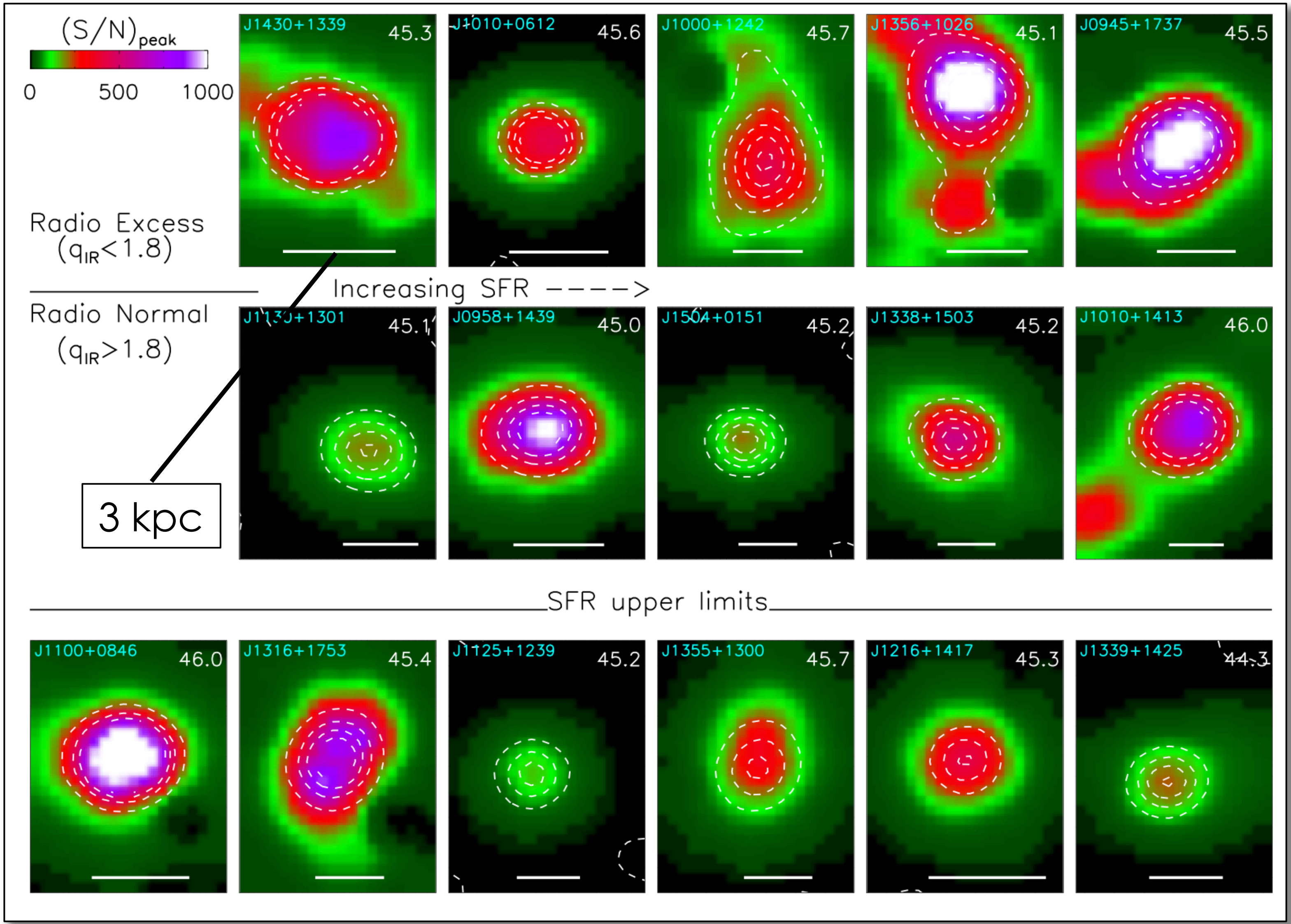


SDSS + IFU data



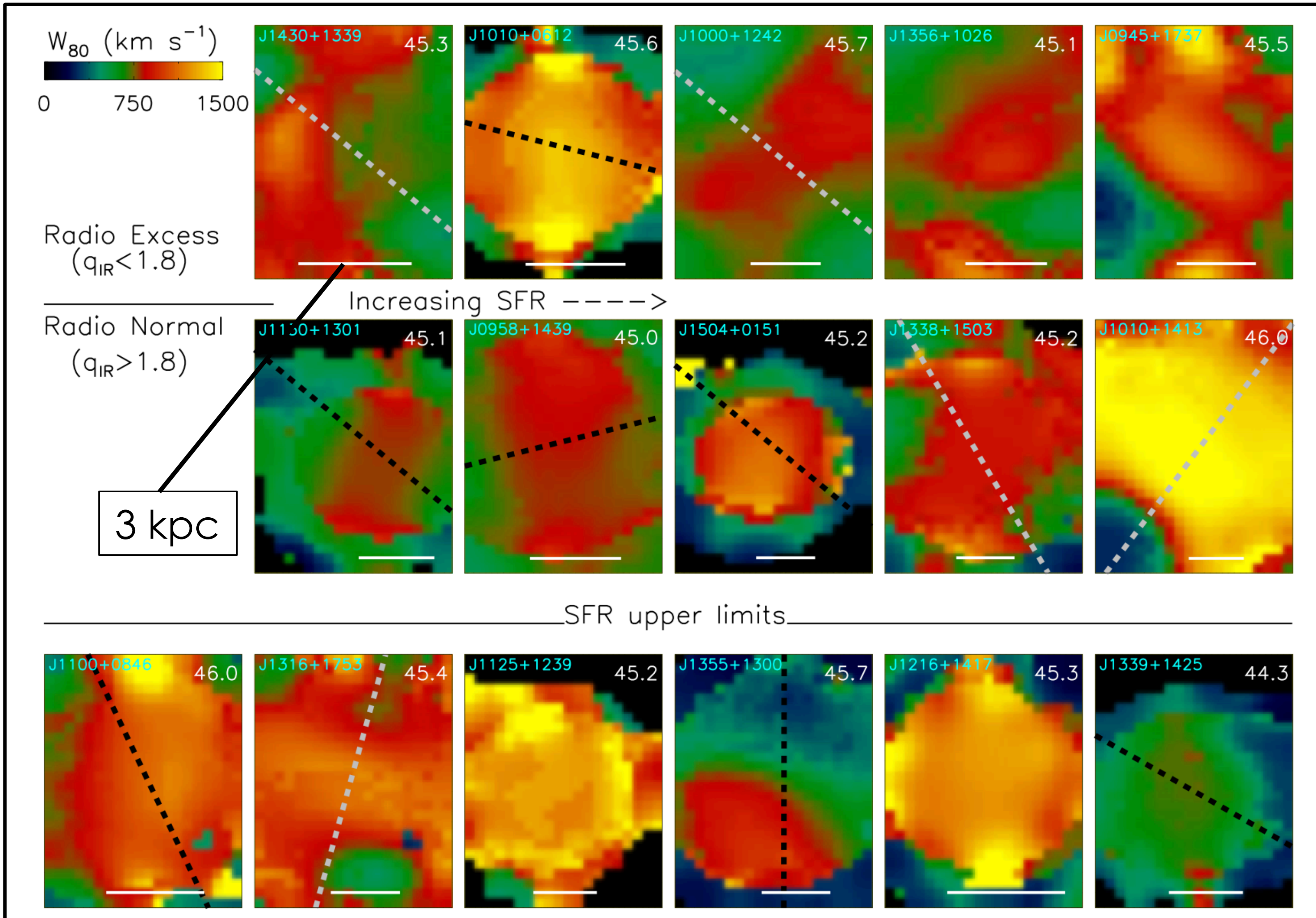
Harrison+14

[O III] emission-line regions



Harrison+14

Spatially extended high-velocity gas



Harrison+14

Galaxy-wide outflows are common

- ~50% of z<0.2 optically luminous type 2 AGN have significant broad [O III] emission-line components (FWHM>700 km/s; SDSS spectra)
- All 16 IFU targets show these components are over kpc scales
- **Therefore: expect >>70%(3 σ) of all the high-velocity components in the parent sample to be extended on these scales**

Properties consistent with models of energy-driven AGN outflows

- *Kinetic energies:* ~0.5-10% of L_{AGN}
- *Momentum rates:* typically ~10-20 x L_{AGN}/c
- *Mass outflow rates:* typically ~10 x SFRs
  (e.g., Hopkins & Elvis 10; Zubovas & King 12; Faucher-Giguere & Quataert 12)

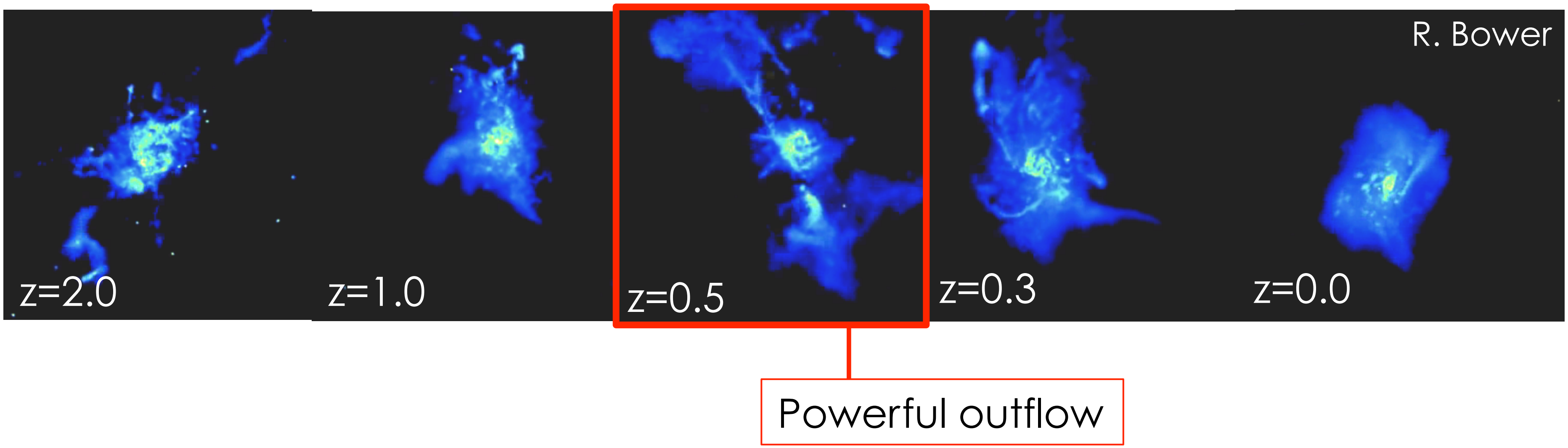
Harrison et al. 2014, MNRAS, 441, 3306

Do luminous AGN have any impact upon SF?

- Outflows could stall in the halo and/or new fuel supplies could re-ignite activity and star formation
- Outflows may have little effect on *current* star formation

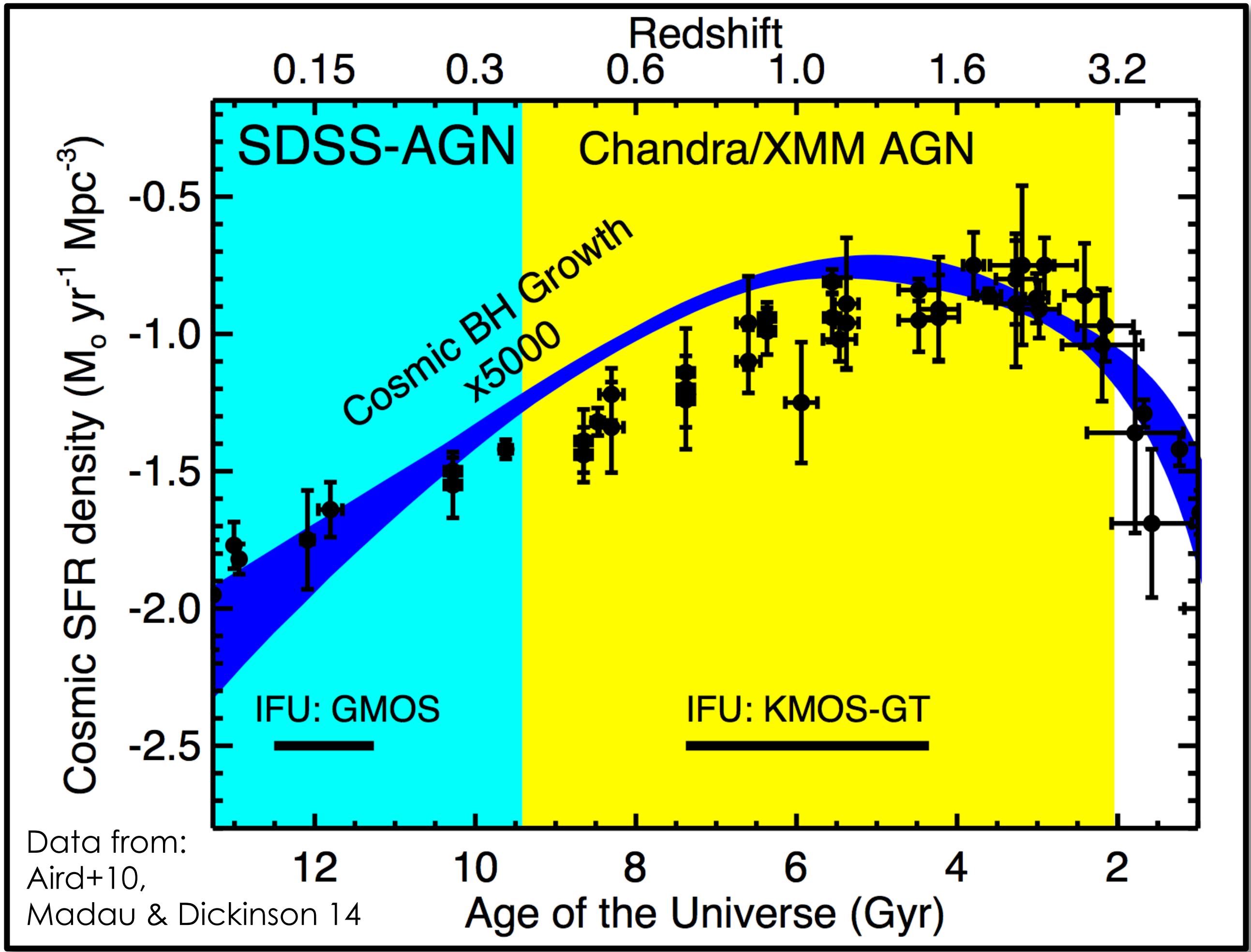
(e.g., Lagos+08; McCarthy+11; Gabor+11,14 ; Roos+14; Rosas-Guevara+14)

***EAGLE*: Durham/Leiden consortium (talks later today)**



Can we find observational signatures of the impact of luminous AGN on star formation in the global population?

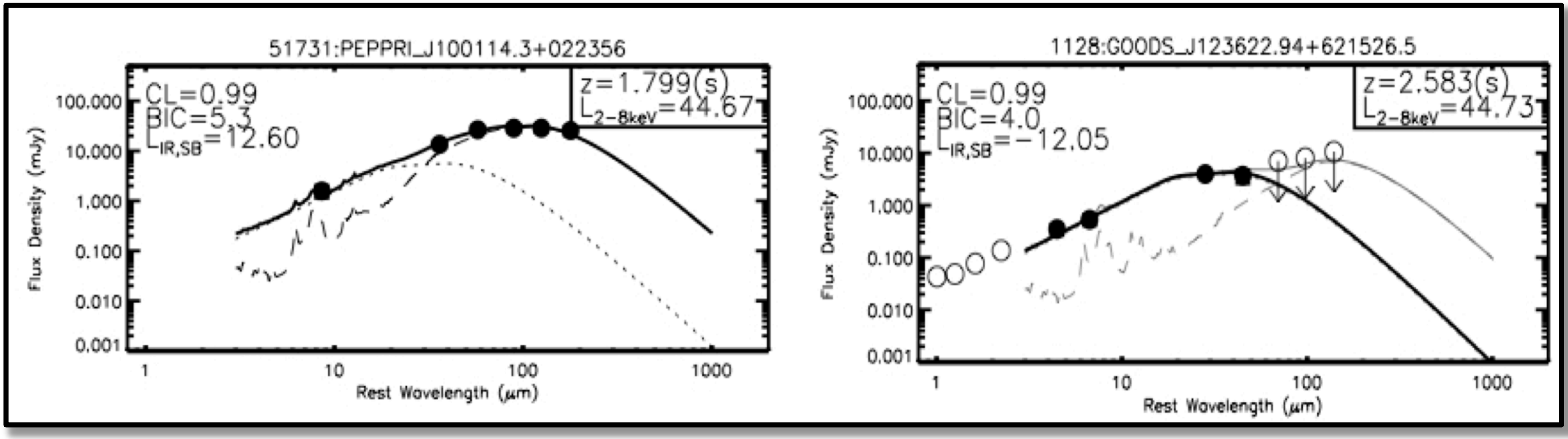
Outflows and feedback in the context of the AGN population



- KMOS: prevalence and properties of ionised outflows at high redshift?
- Is there any impact on star formation from luminous AGN?

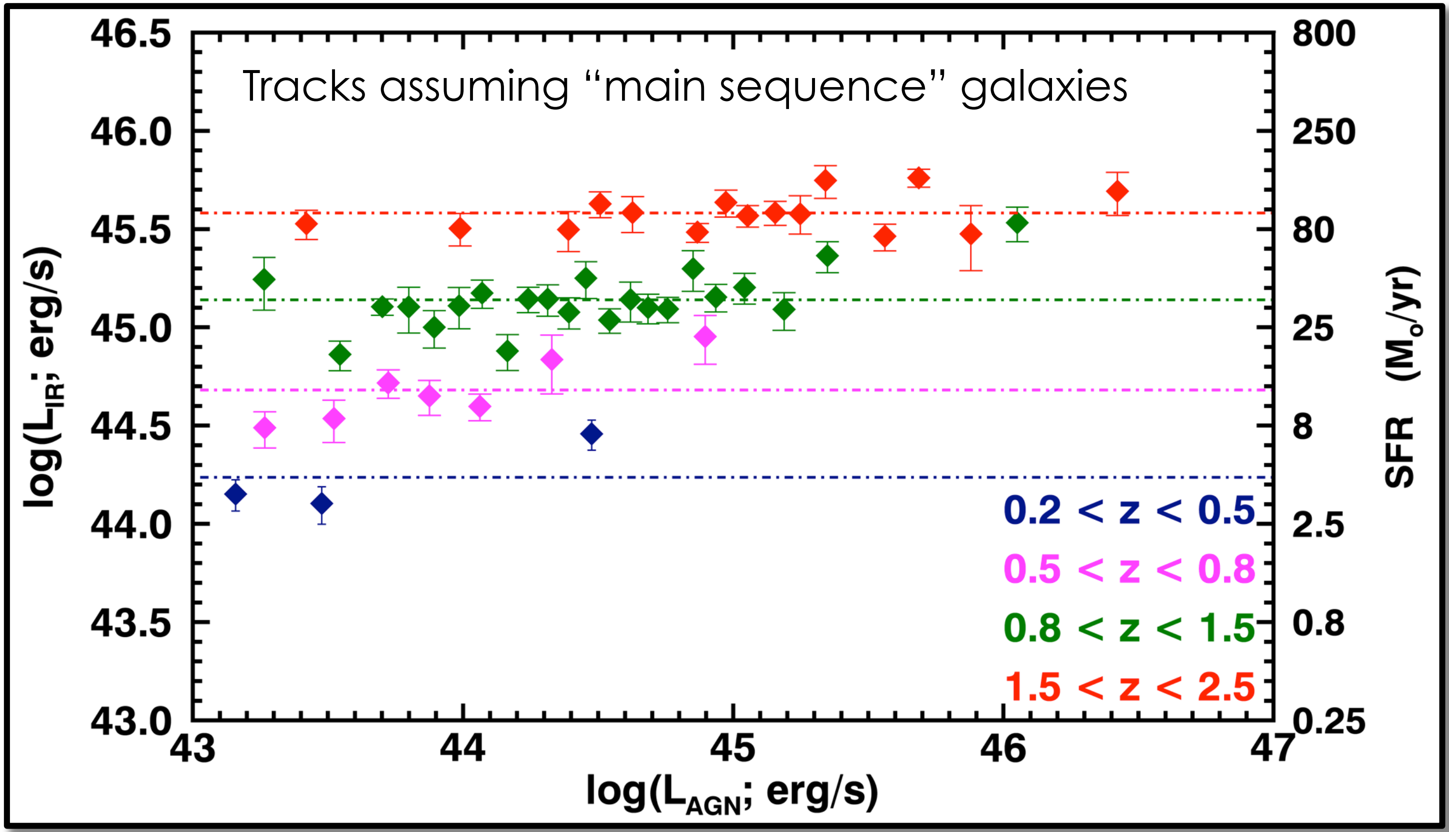
Carefully constraining SFRs for ~2200 individual AGN

- ❑ **~2200 AGN from Chandra and XMM (COSMOS/CDF-S/CDF-N)**
- ❑ **Photometry from MIR-FIR** (IRAC, Spitzer, Herschel).
  - + Using *de-blended PACS/SPIRE* Herschel data (Magnelli+13; Swinbank+14)
  - + Upper limits are derived for all sources not detected
- ❑ **SED fitting to de-compose SF and AGN** (following Mullaney+11, Del Moro+13)
  - + SFR upper limits determined for sources when insufficient data or when AGN dominated
- ❑ Use survival analysis to **calculate mean SFRs** taking into account upper limits.



Stanley, Harrison + in prep (poster A10)

What do simple model prescriptions predict?



Stanley, Harrison + in prep (poster A10)

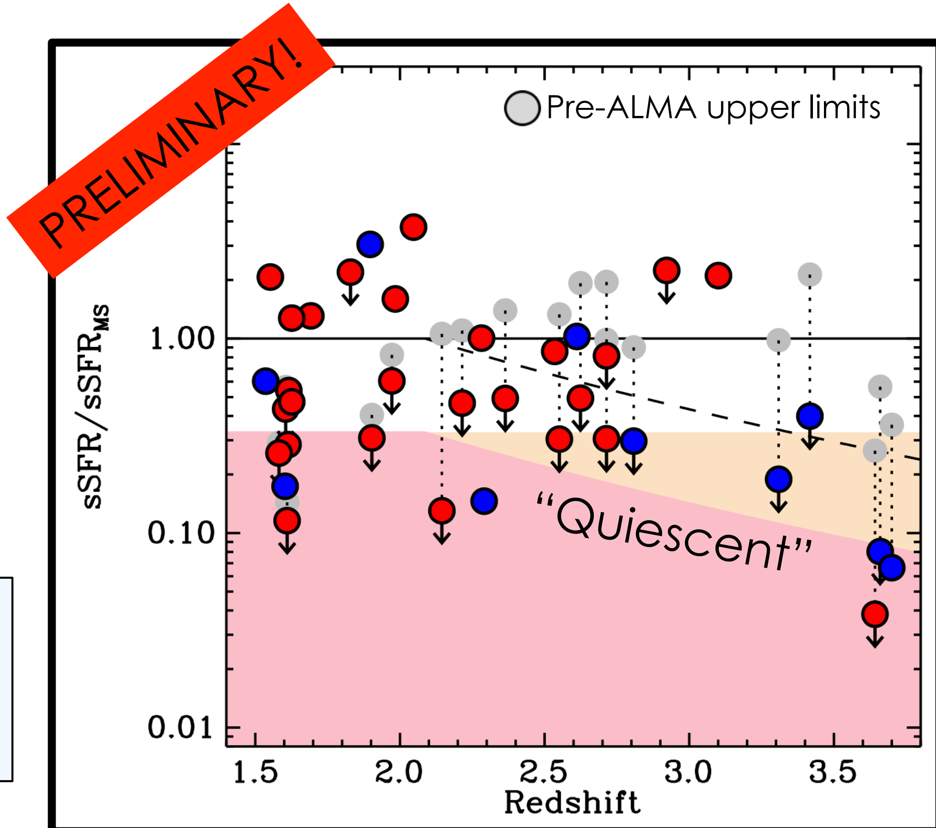
- Overall AGN have <SFRs> broadly consistent with non-active star forming galaxies
- Possible up-turn of <SFR> at high L_{AGN}
- Does this mean no suppression? Why are they not correlated?
- We are comparing to various model predictions

Beating down the upper limits with ALMA

Two large ALMA programs (Cycle 1 and Cycle 2; 850um continuum) to get even better SFR constraints for ~100, z~1-3 AGN:

- ALMA 850um data in agreement with our earlier SED-based SFRs
- However, **at ALMA depths upper limits can be decreased by a factor of ~1.5-7**

Enables us to measure the "quiescent fraction" for high-z X-ray AGN using FIR-derived SFRs.



Mullaney + in prep

Conclusions

- Ionised kpc-scale outflows are extremely common in low-z type 2 quasars
- The mean SFRs of luminous (L_X >~ 10^{43-44} erg/s) AGN are consistent (or slightly enhanced) compared to lower-luminosity AGN (z~0.2-3.5)
- We have ongoing KMOS and ALMA programs to tie together the properties of outflows in AGN and the impact (or not) of luminous AGN on star formation at high redshift

Mixed results on the SFRs of luminous AGN

Many studies of high-z X-ray AGN have used Herschel to obtain mean SFRs

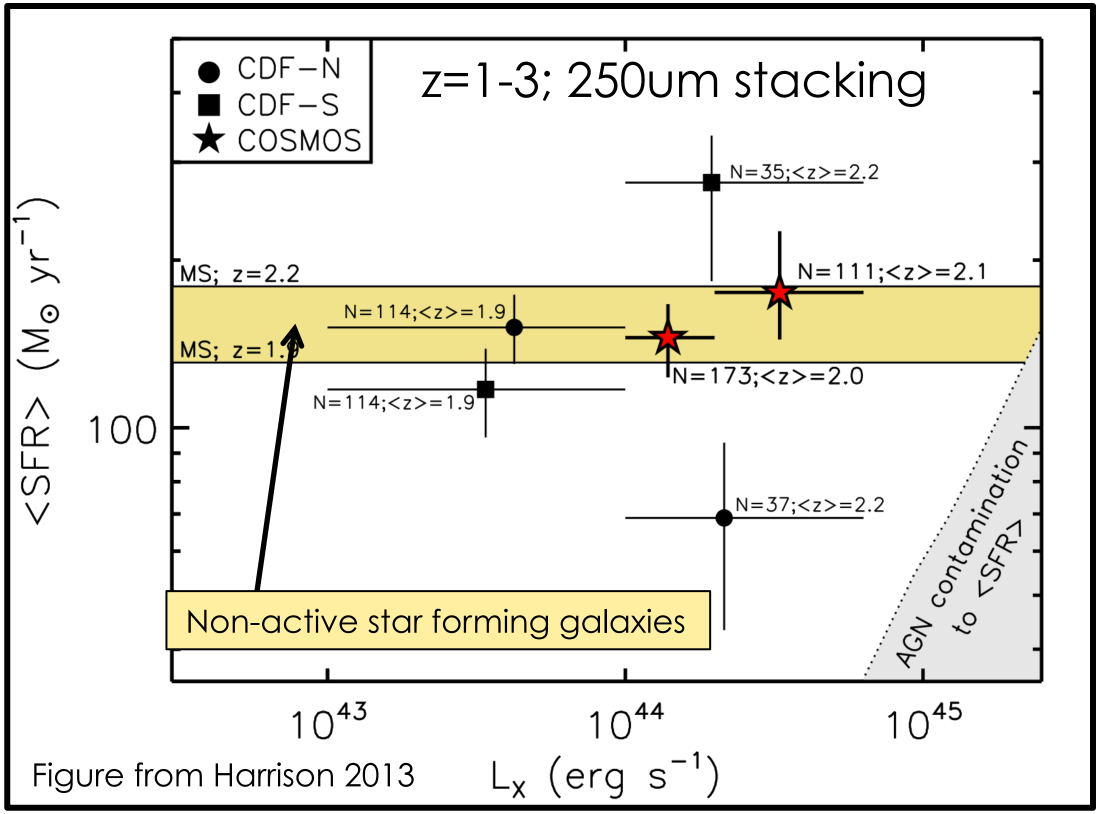


Figure from Harrison 2013

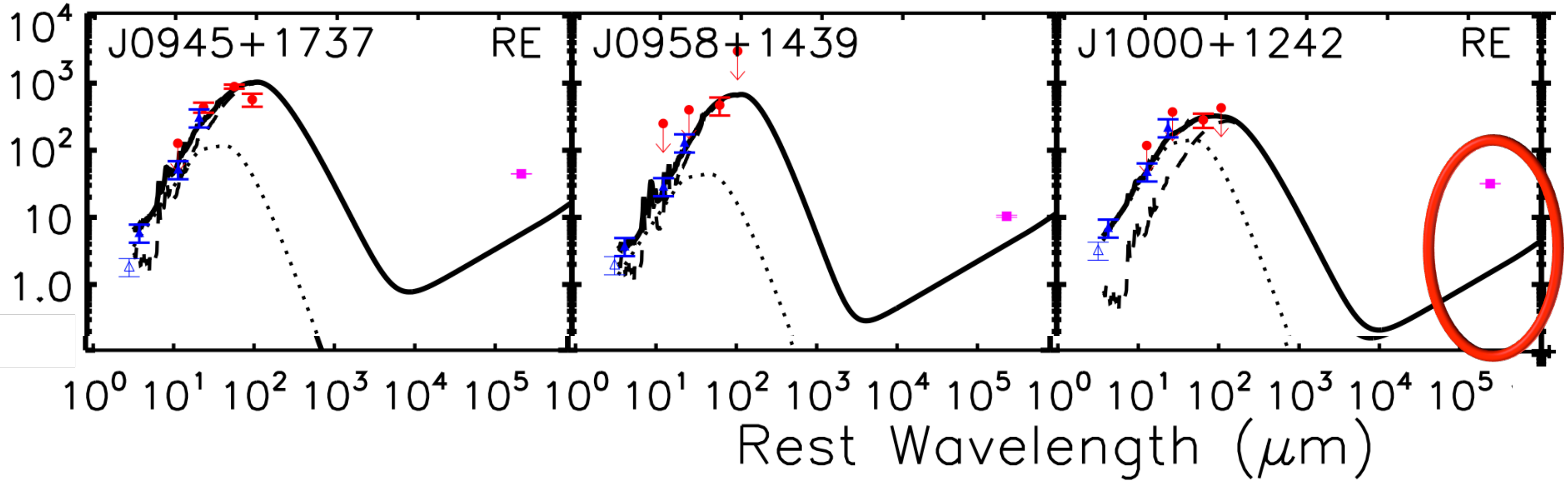
- At low X-ray luminosities SFRs consistent with non-active star forming galaxies (e.g., Mullaney+12; Rosario+12)
- For luminous AGN (L_X >~ 10^{44} erg/s), studies say SFRs are higher, lower or the same. (e.g., Page+12; Rovilos+12; Rosario+12)
- Different results are at least partially driven by small studies in different fields

Harrison+12b

But what about: AGN contamination, limitation of stacking etc…

Measure SFRs, AGN luminosities, radio properties

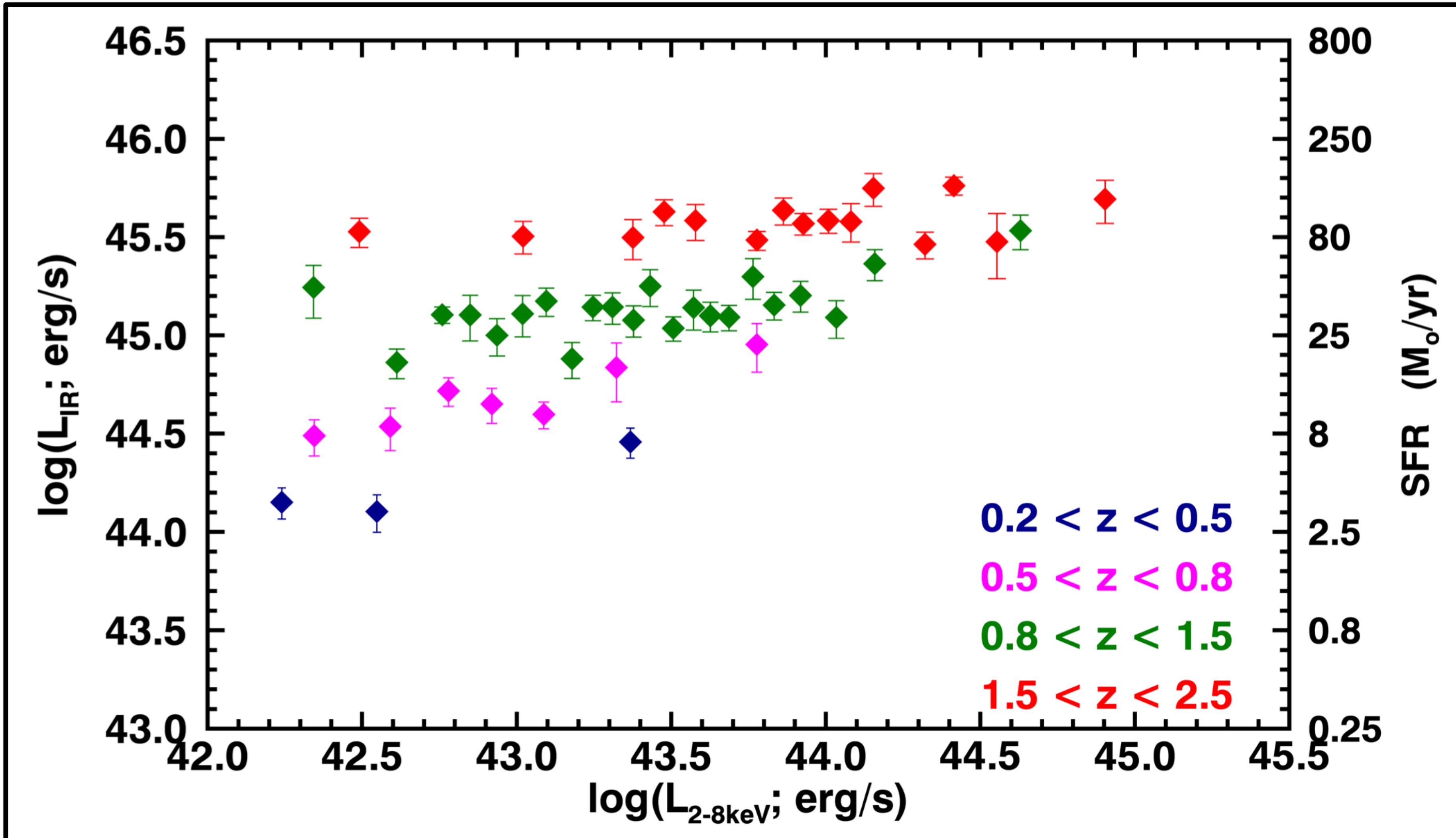
- MIR-FIR SED fitting
- AGN luminosities: (0.2 – 10) x 10^{45} erg s^{-1} (mostly quasars)
- SFRs <7 ~ 100 M_o/yr (typical for quasars at this redshift)



- Radio quiet ($L_{1.4GHz}$ = ~10^{23} – 10^{24} W Hz^{-1})
- *5 sources:* clear radio-excess (above SF):
- *5 sources*: radio is *consistent* with SF-only
- *6 sources*: unable to constrain (no IRAS detections)

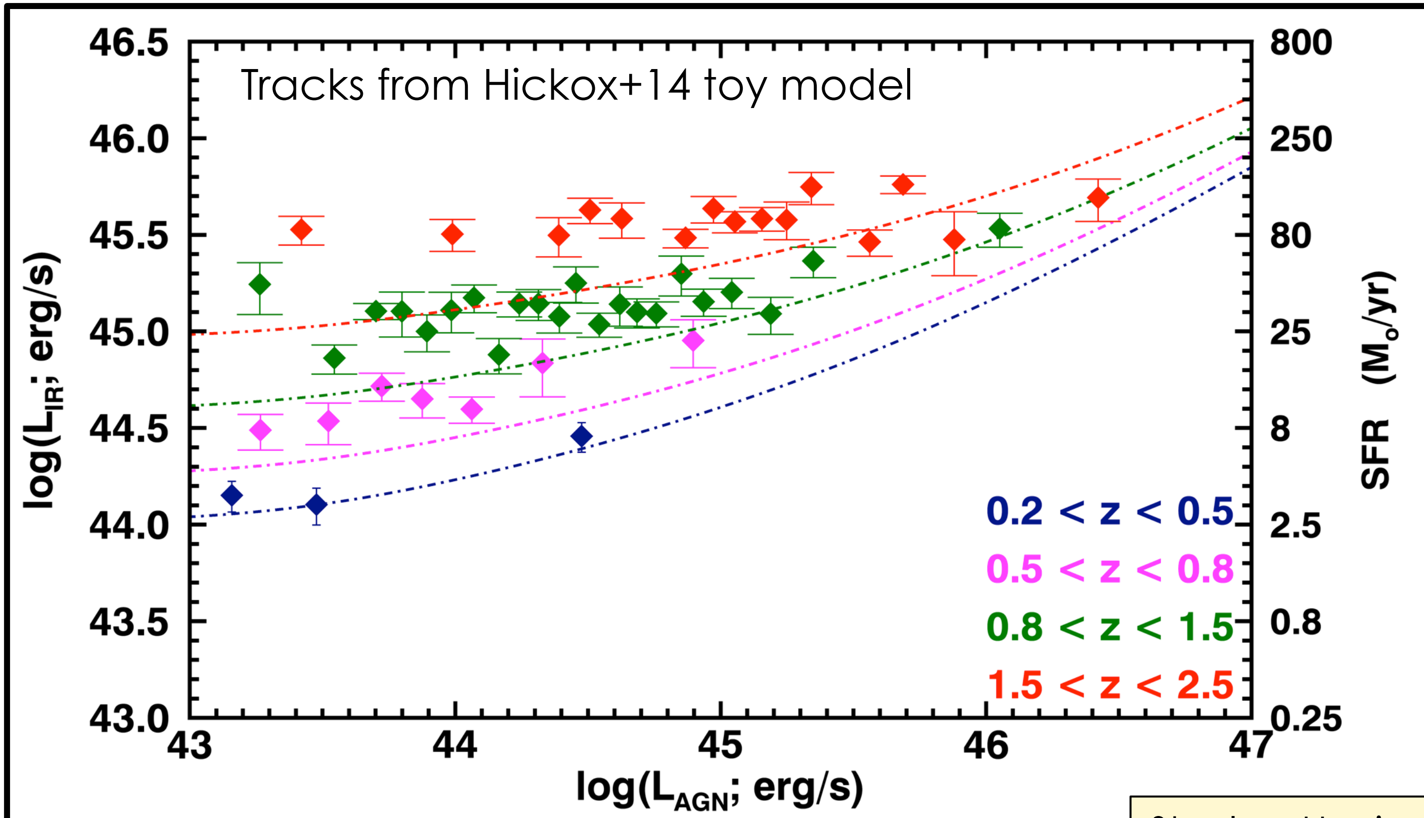
Harrison+14

SFR as a function of AGN luminosity



Stanley, Harrison + in prep

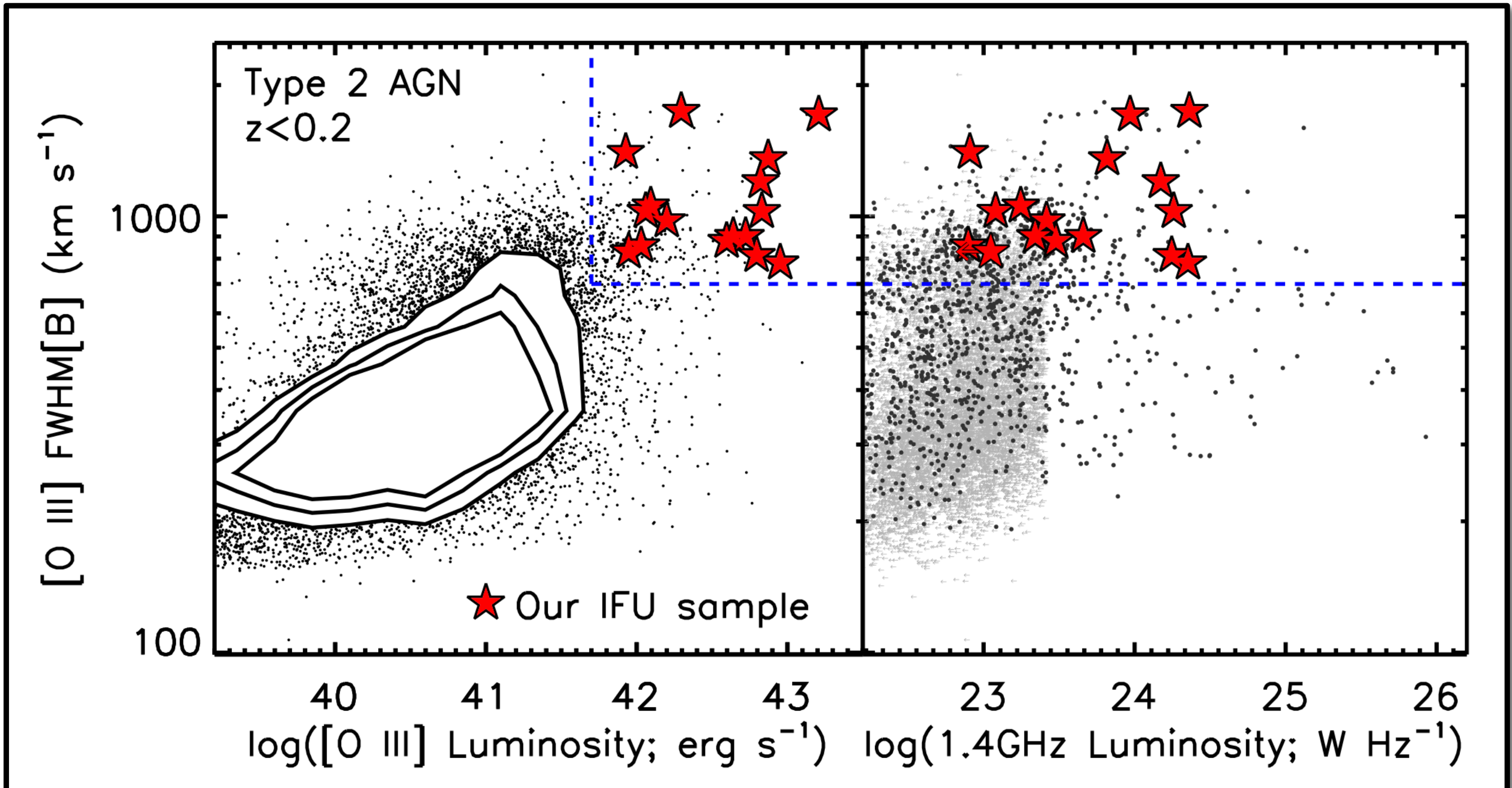
What do simple model prescriptions predict?



Stanley, Harrison + in prep

- ❑ Even if you assume, when averaged over time, SFRs and AGN luminosities are correlated you need to include a prescription for variability (Hickox+14).
- ❑ This introduces a flattening of the relationship, especially at low L_{AGN}

IFU targets: well constrained parent sample

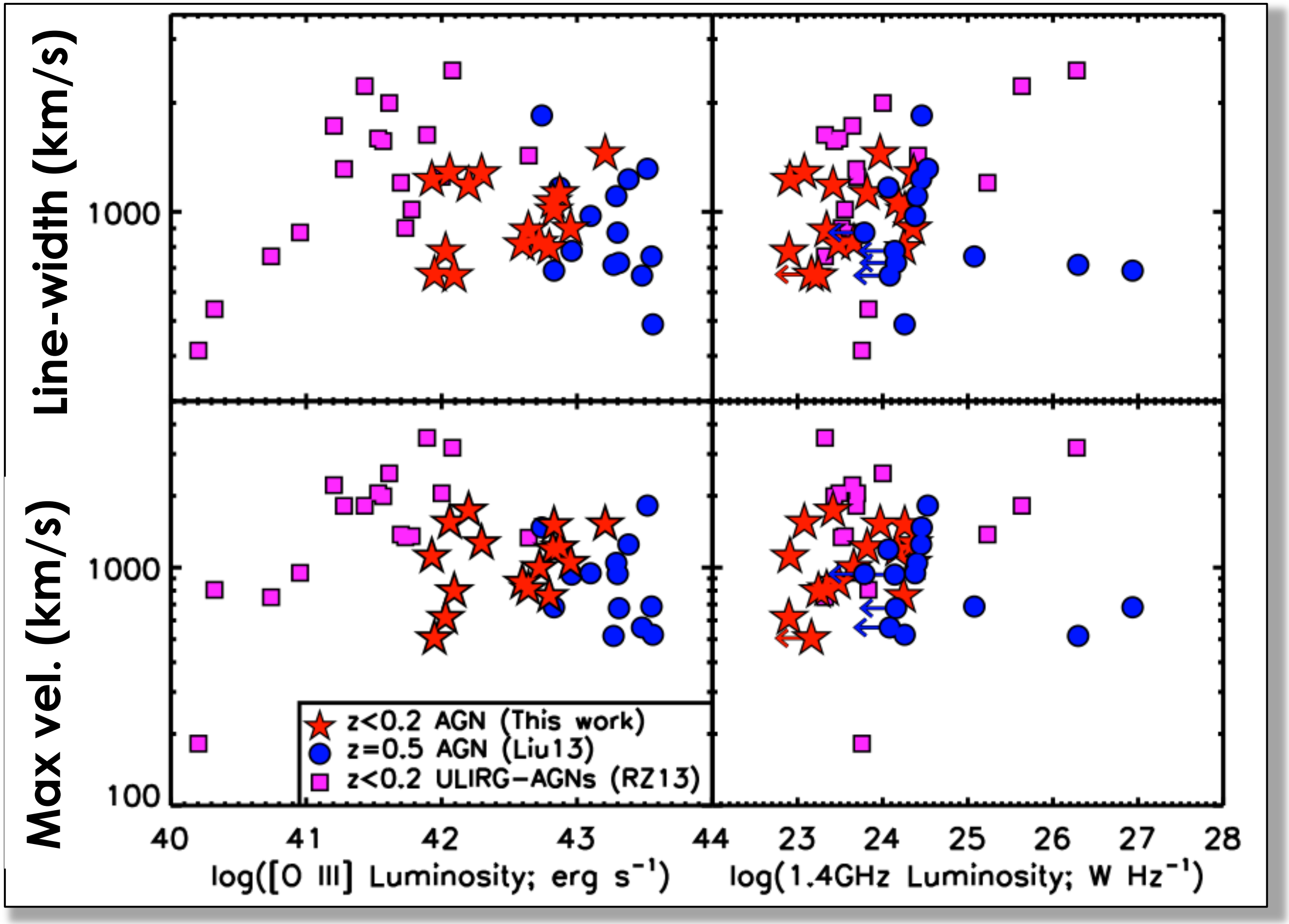


- Parent sample from Mullaney et~al. 2013 (~24,000 SDSS z<0.4 AGN)
- Consider z<0.2, type 2 AGN; luminous ($L_{[O\ III]}$ > 5 x 10^{42} erg/s)
- 45% of these have significant broad component (FWHM > 700 km/s)

Harrison+14

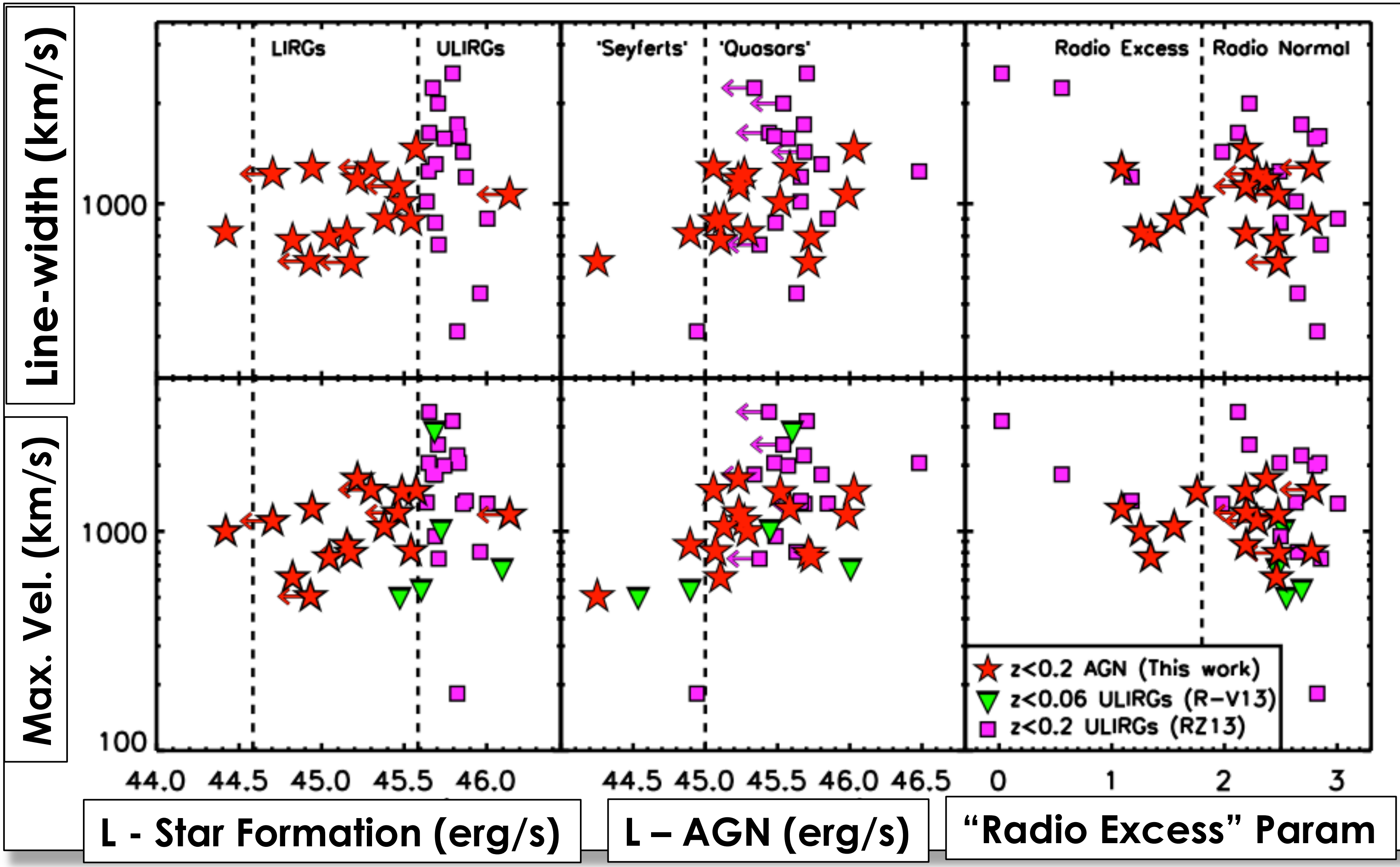
Comparison to other samples

Harrison+14



- "Typical" radio luminosities
- High velocity ionised gas is seen over a large luminosity range

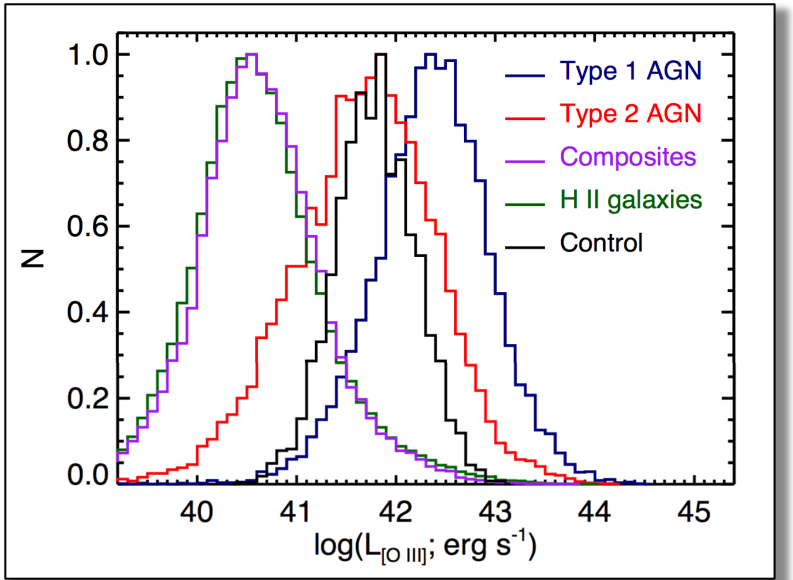
Outflow properties vs. AGN, SF, Radio



Harrison+14

- ULIRGs shows most extreme velocities
- Possible trends with AGN luminosity

Comparing to non-active H II galaxies



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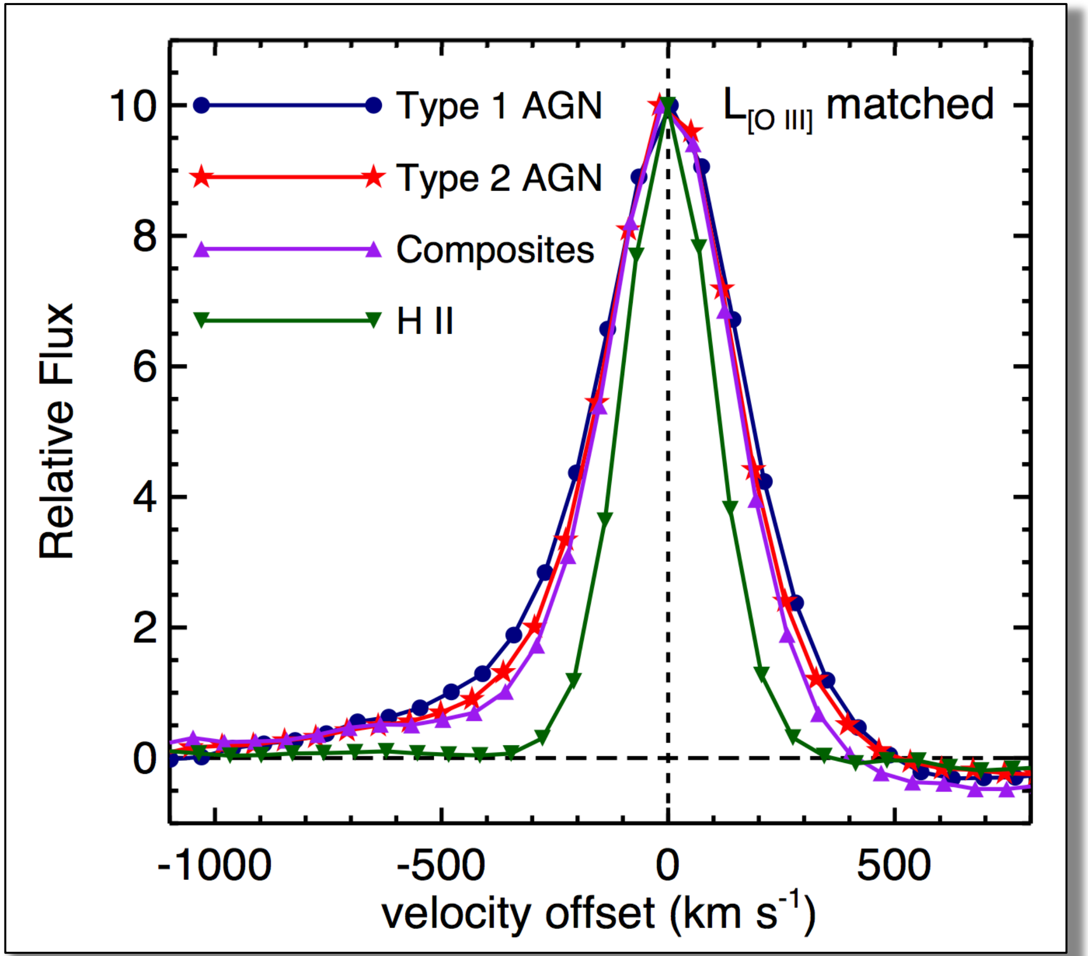
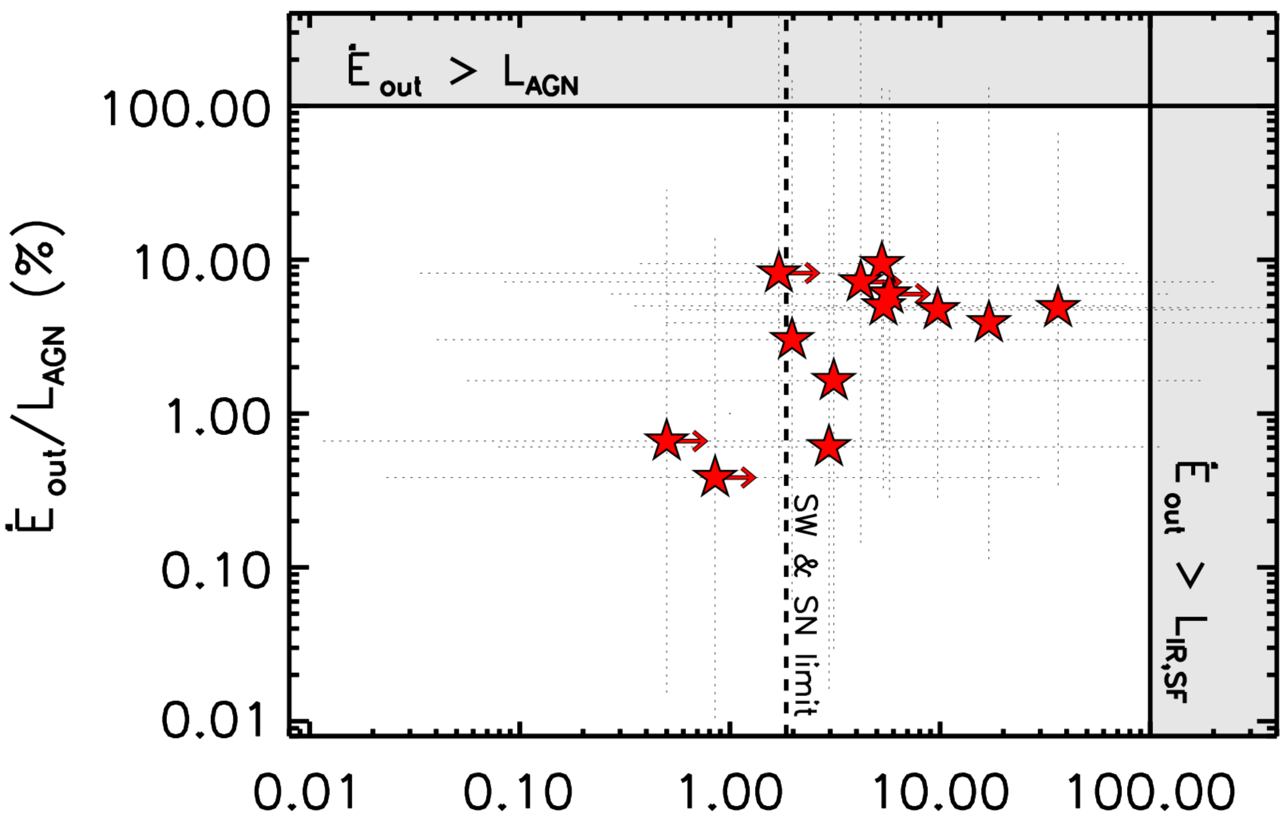


- Take all z<0.4 with emission-line detections (SDSS DR7)
- Luminosity ([O III]) match samples
- AGN show stronger blue wings than H II galaxies

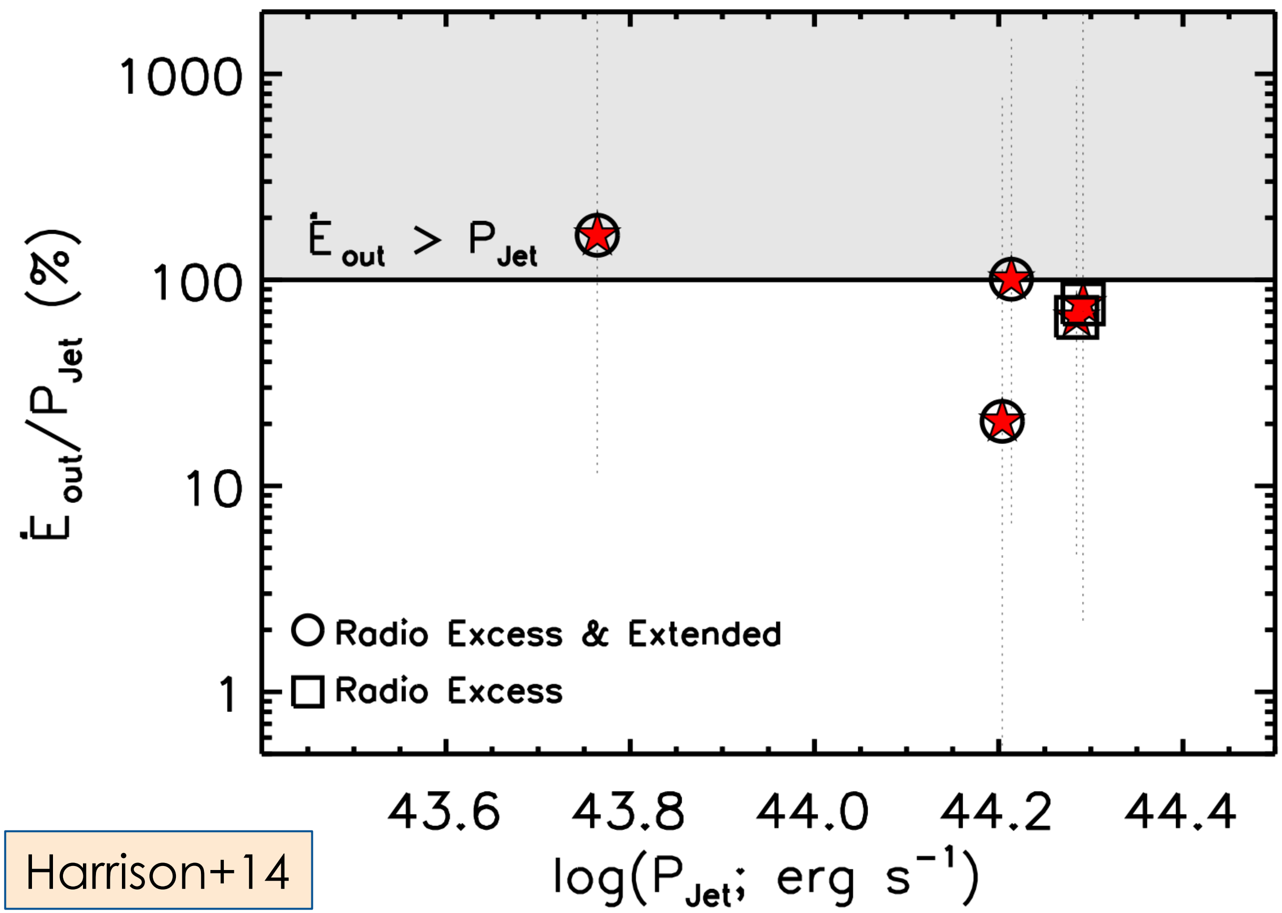
Coupling Efficiencies



Harrison+14

- Outflow rate ~0.5-10% of L(AGN)
- Outflow rate >~0.5-40% of L(SF)
- However, difficult to explain with SN or Stellar winds alone (following e.g., Leitherer+99)

Coupling Efficiencies: Jets?

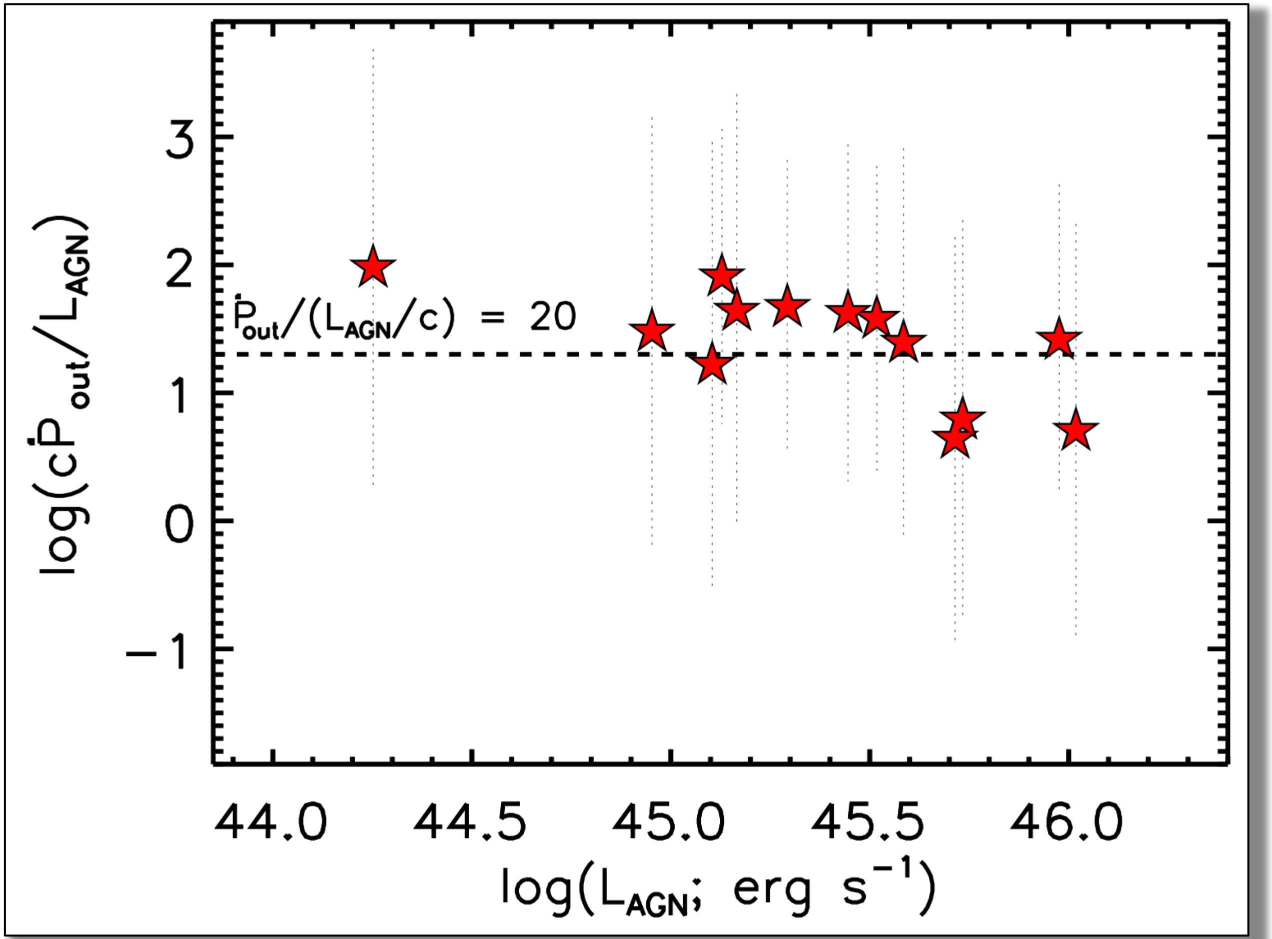


Harrison+14

- ~20% - >100% efficiencies required
  (although see e.g., Wagner+12)

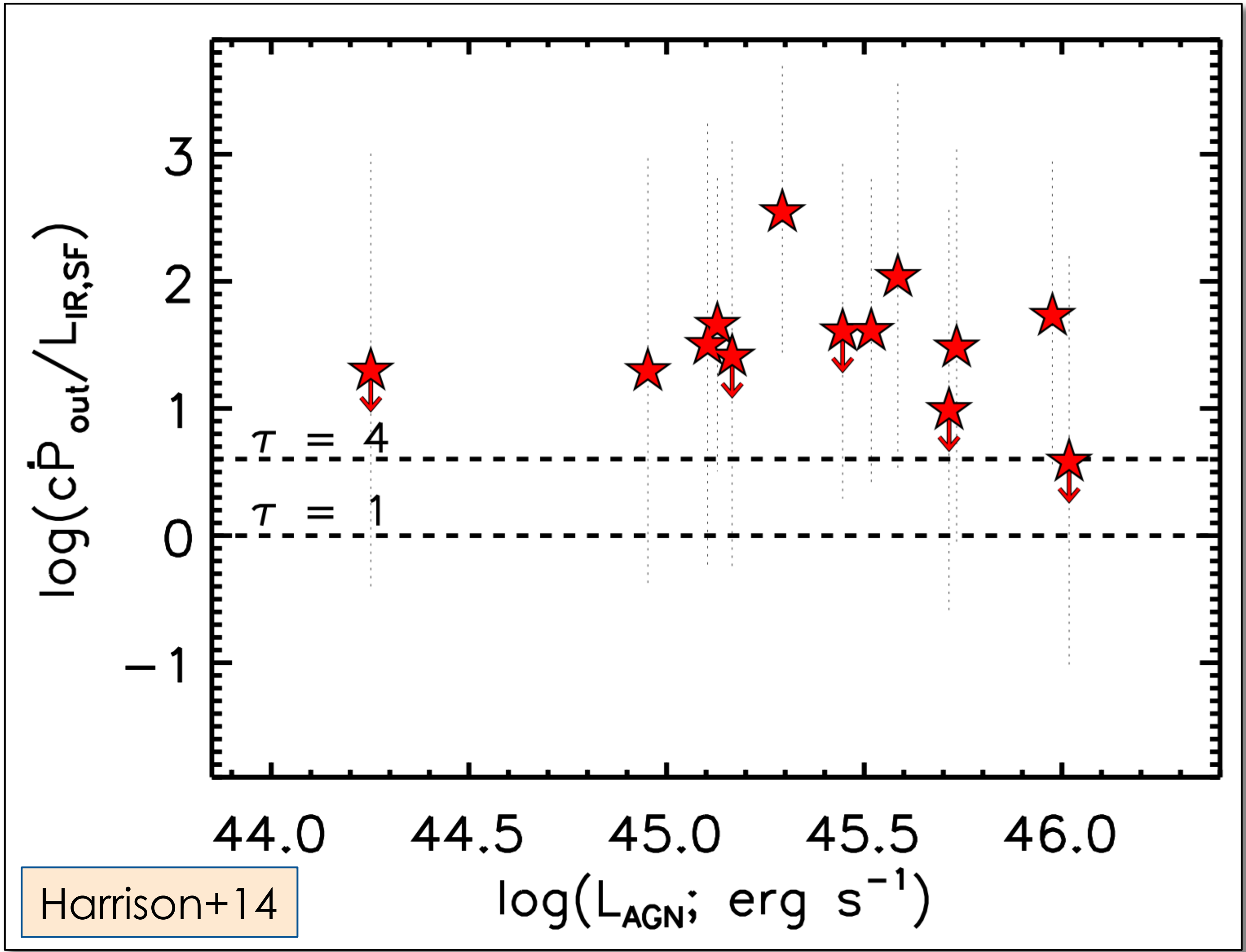
Momentum Rates: AGN

Harrison+14



- Momentum rates / [L(AGN)/c] >= 10 on kpc scales
- Consistent with energy-driven AGN outflows
  (e.g., Faucher-Giguere+12; Zubovas & King 2012; Debuhr+12)

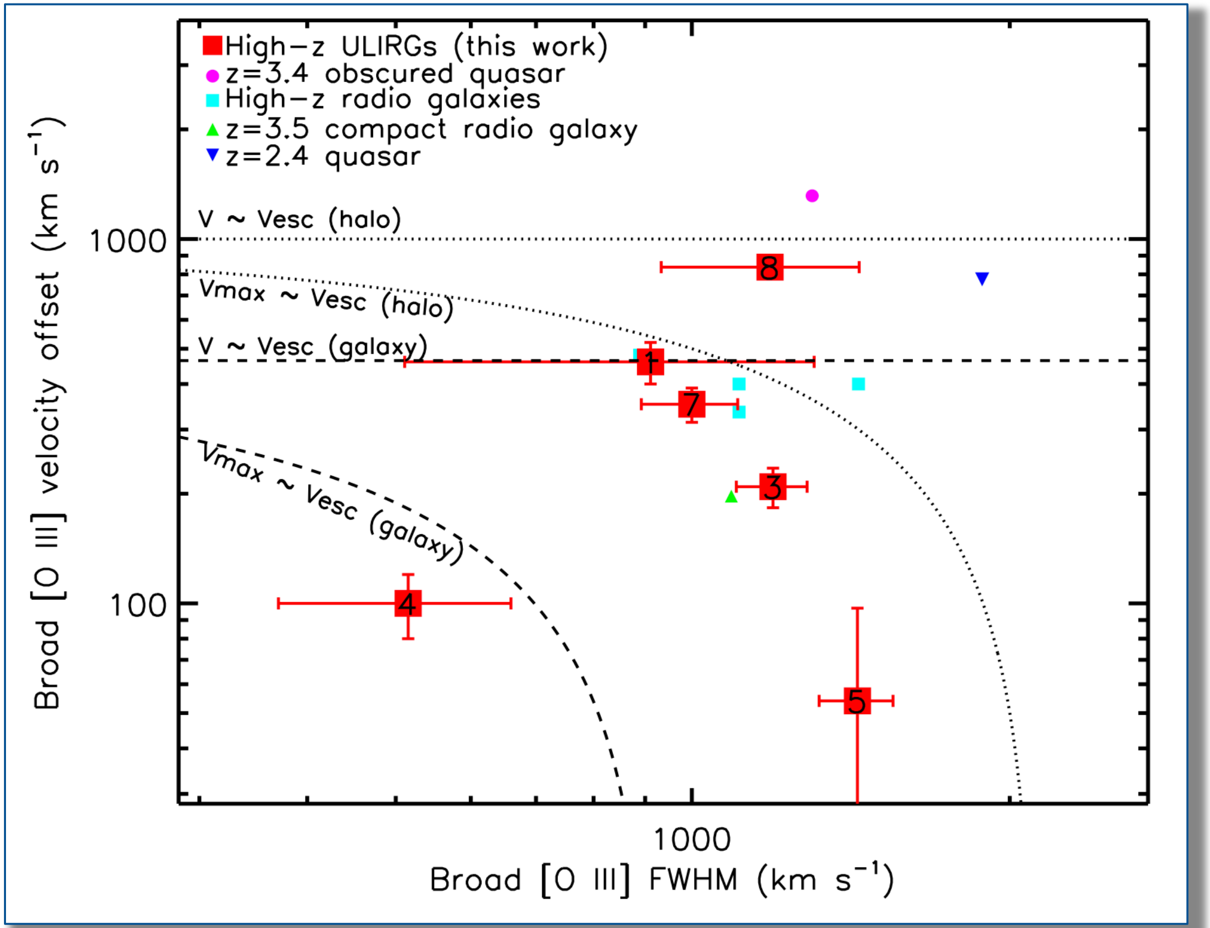
Momentum Rates: Star Formation



- Implies not radiatively driven by star formation

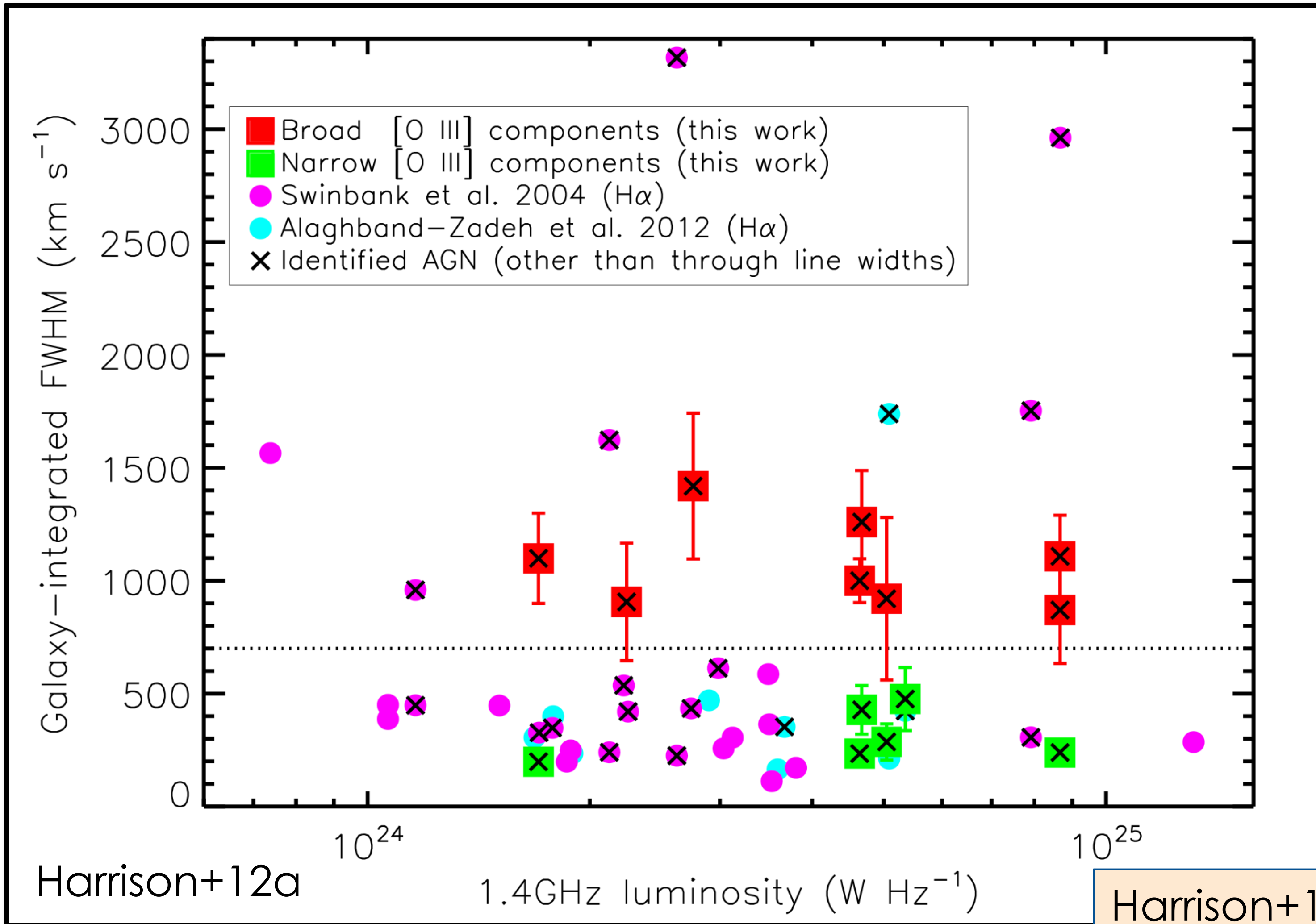
High-z ULIRG/AGN: Can the gas escape?

Harrison+12a



- Consider v(max) = v + FWHM/2
- Velocities high enough to escape galaxy
- However, gas may not escape halo

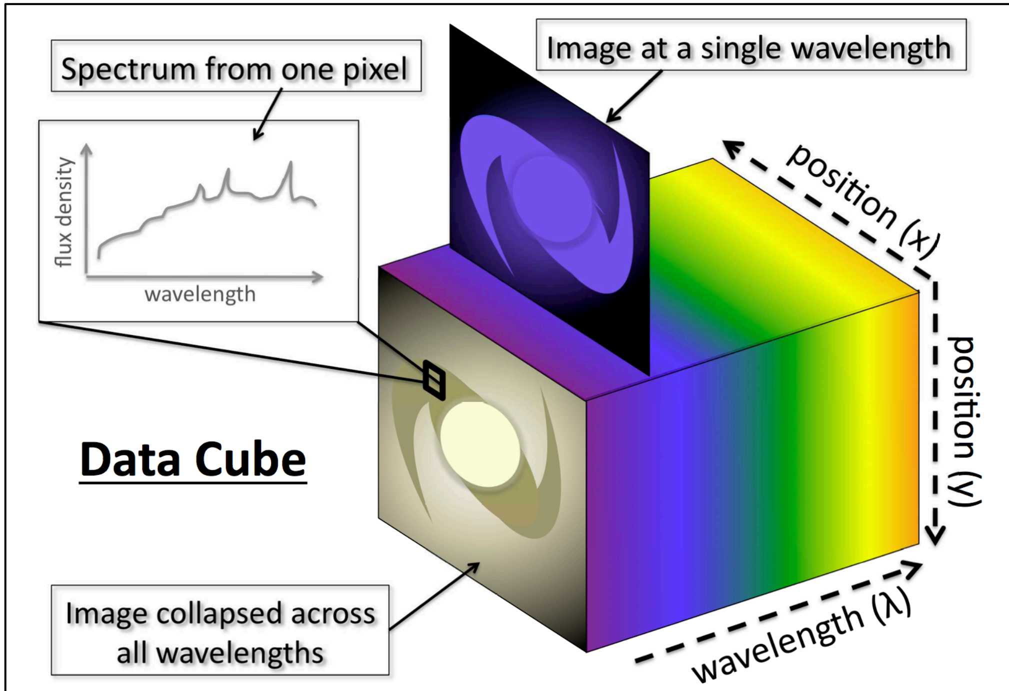
High redshift ULIRGs



Harrison+12a

- AGN hosts show the highest velocity ionised gas

Searching for extended, ionised outflows: IFU observations



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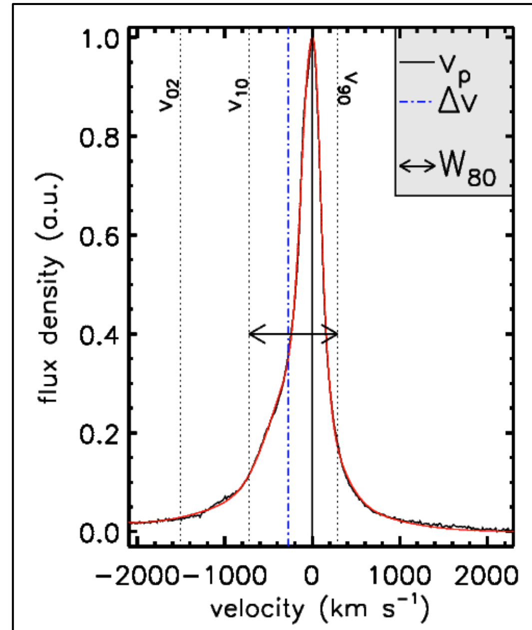
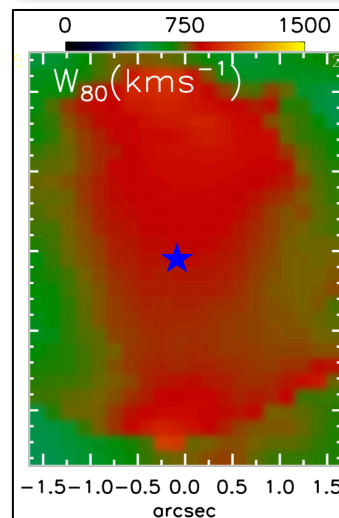
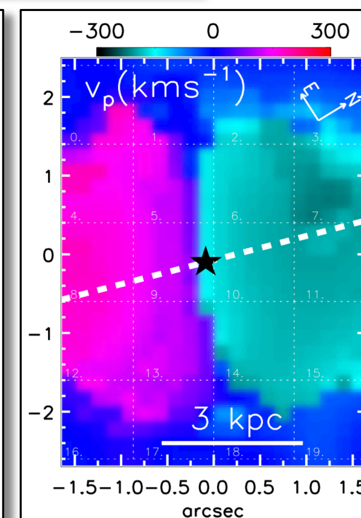


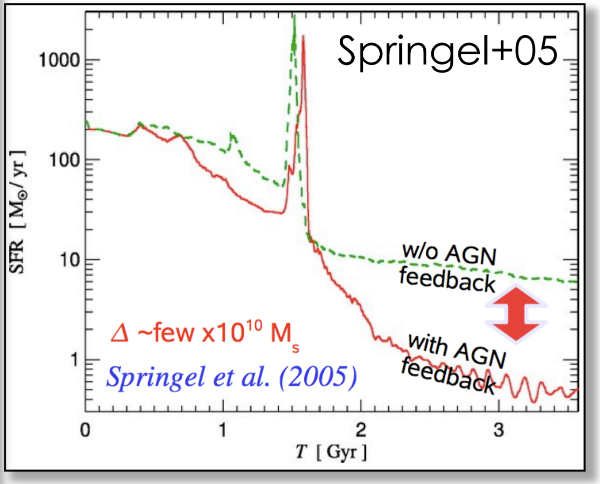
Harrison+14

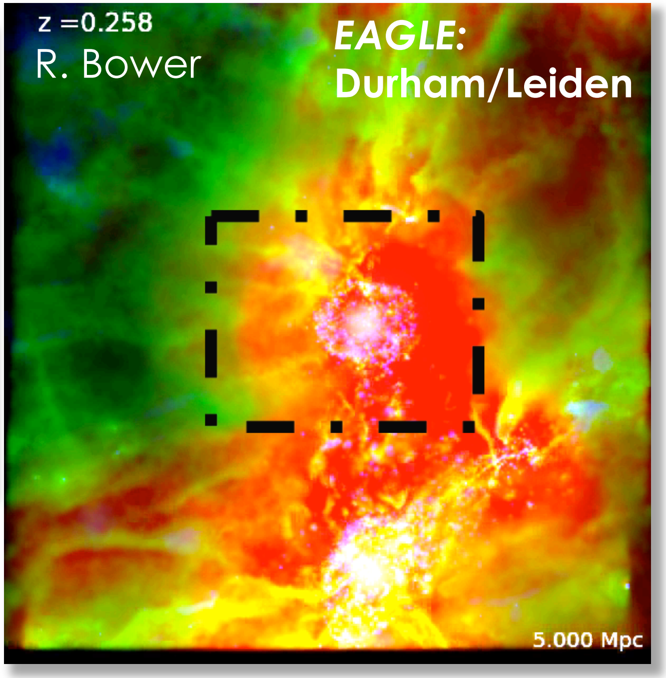




- Kinematic structure
- Spatial extents
- Morphologies
- Energetics / mass outflow rates

Galaxy-wide quasar-driven outflows: models





Have been predicted to :

- Suppress (or enhance) SF;
- Remove low-entropy gas from groups;
- Set M-sigma relationship;
- Re-distribute metals

- What are their observed properties?
- What drives them?
- How common are they?
- What impact do they have?

e.g., Benson+03; Granato+04; King+05,11; Hopkins+06; Bower+08; Ciottii+10; Faucher-Giguere & Quataert 2012; Nayakshin & Zubovas 12; Wagner+13 ; Bourne+14