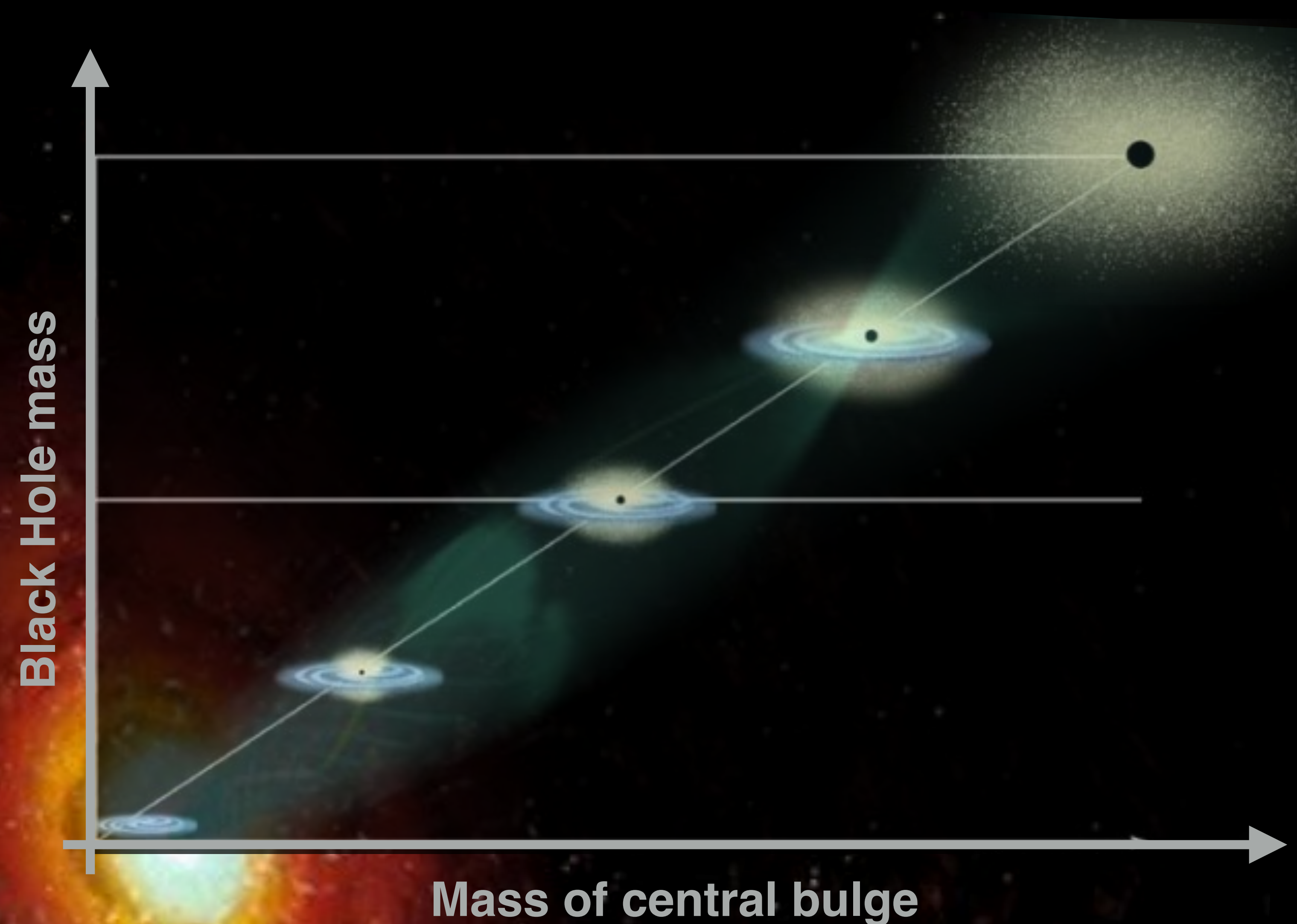
# Unveiling the role of radio jets to the AGN/Star-formation connection

**Eleni Kalfountzou**

**In collaboration with: J. Stevens, M. Jarvis, M. Hardcastle, M. Trichas, M. Elvis**




University of Hertfordshire

# Once upon a time...

**Host Galaxy**

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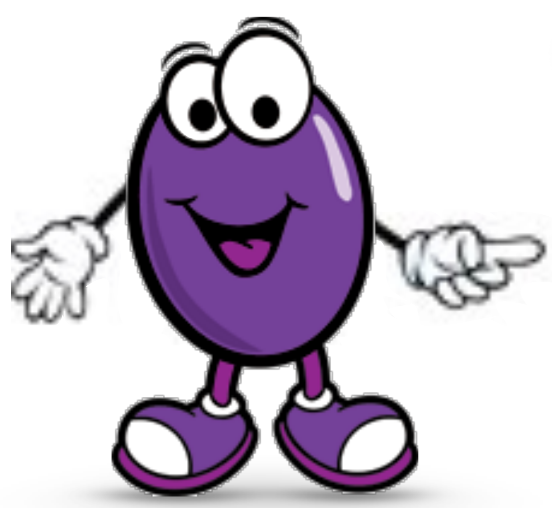
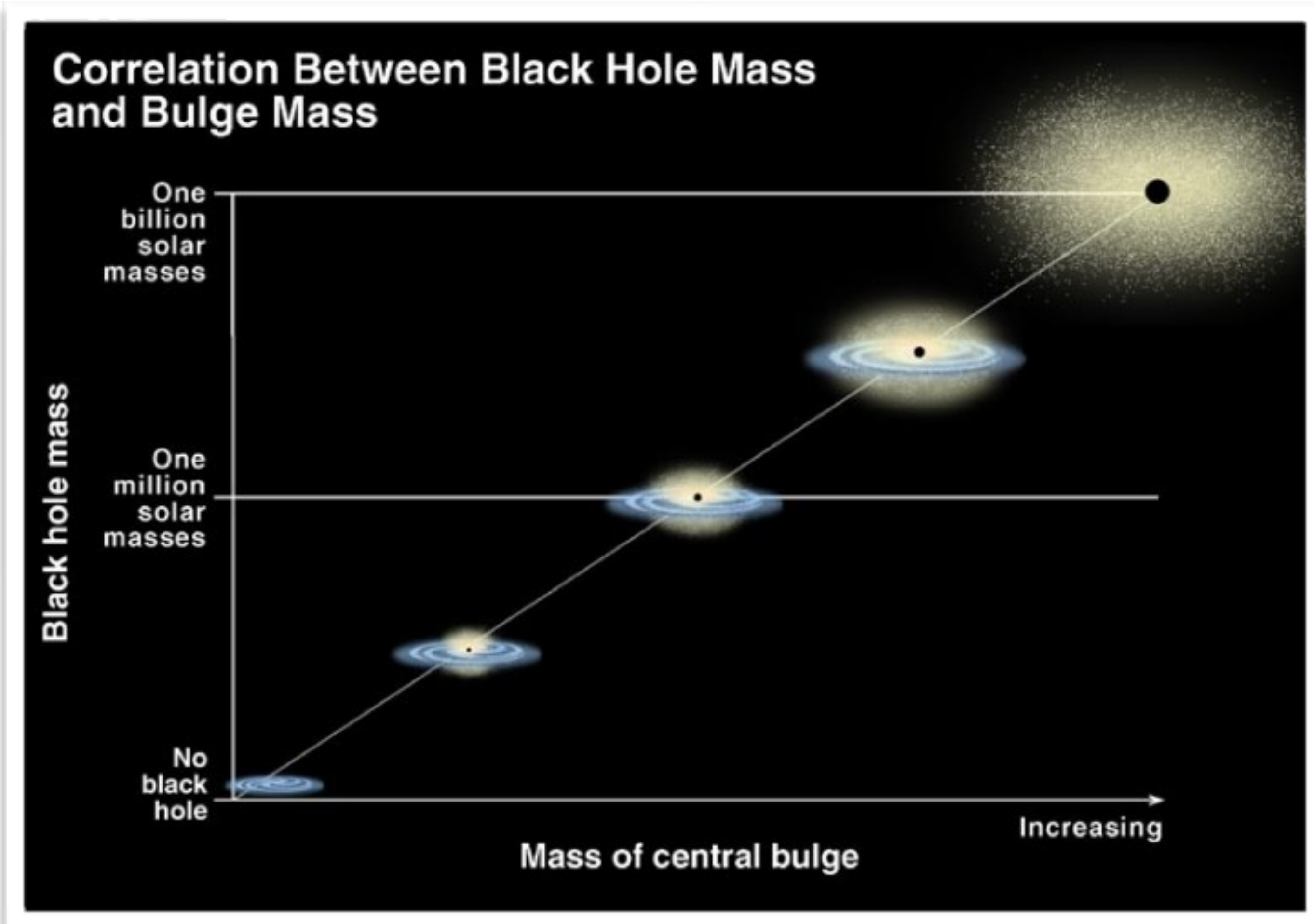
Host Galaxy

Connection?



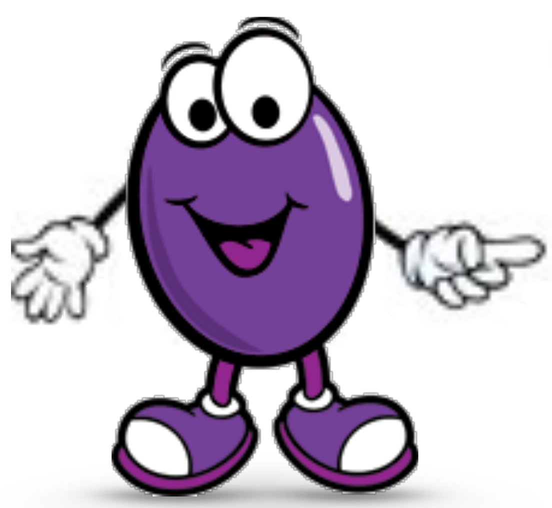
Black Hole

*We can influence each other*




**e.g.** Magorrian et al. (1998); Ferrarese & Merritt (2000); Gebhardt et al. (2000); Tremaine et al. 2002; Marconi & Hunt (2003); Gultekin et al. (2009)

**Host Galaxy**

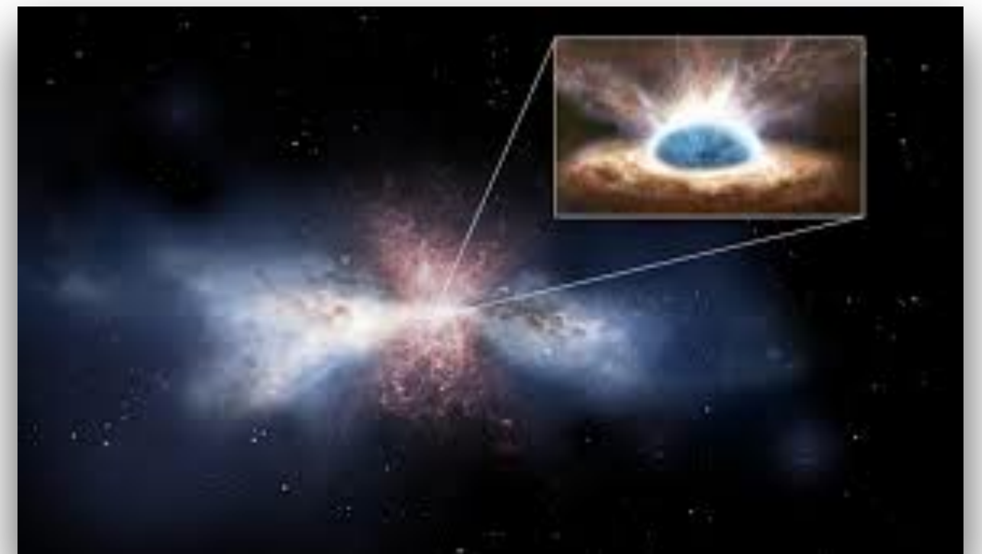


**Black Hole**

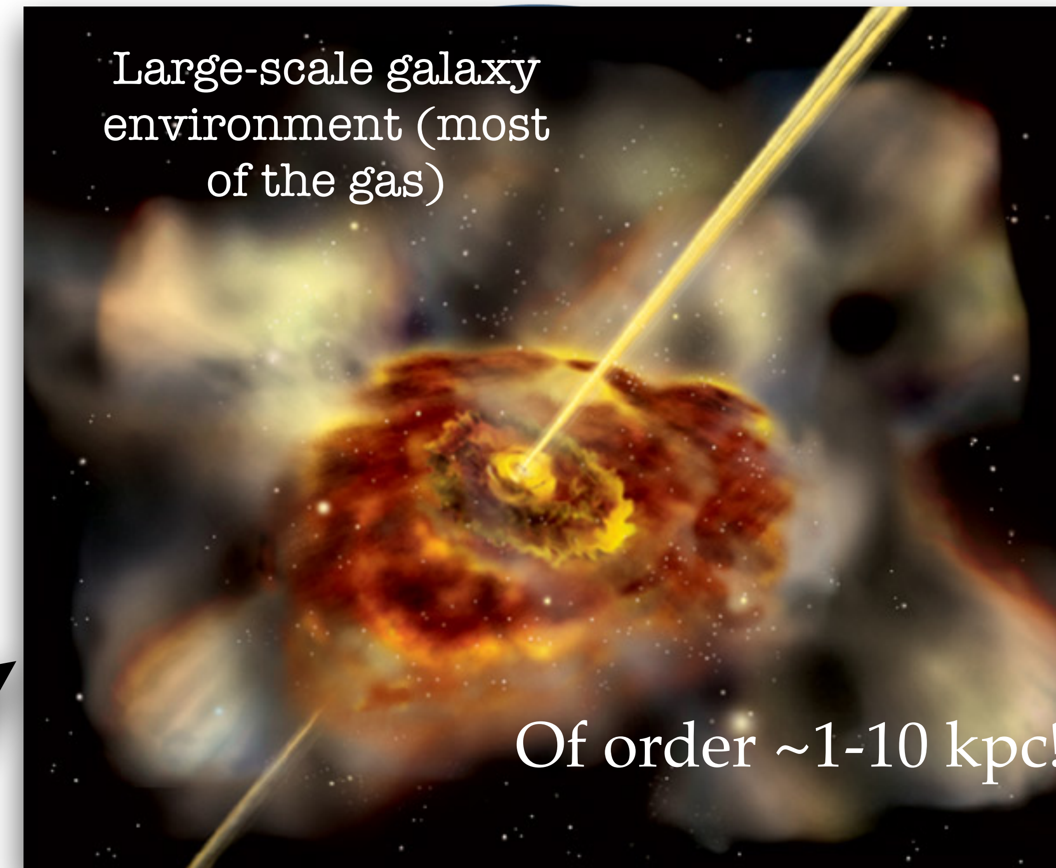
Black-hole-galaxy: ~$10^9$ difference in size scale (grape-Earth) – how can one know about or influence the other?!

# The AGN impact on the host galaxy

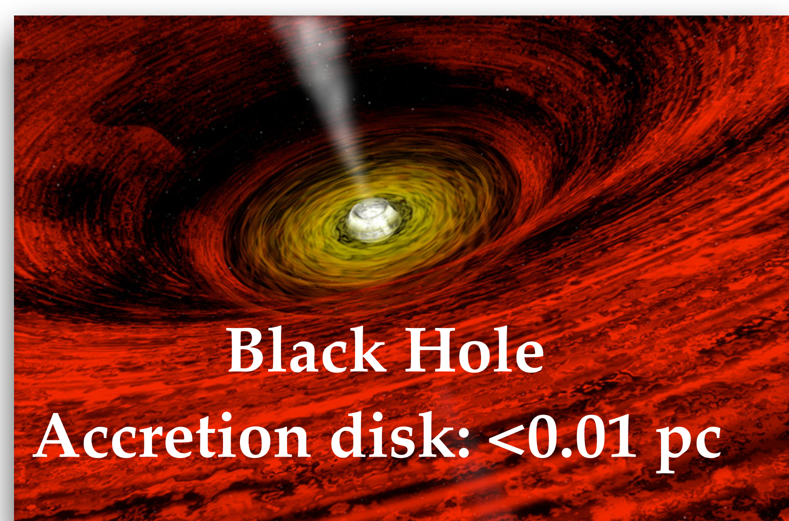
Superwind expels cold gas reservoir



Credit: NASA's Goddard Space Flight Center




Connection?




"Cross-Talk" = Feedback

Large number of different mechanisms

Regulate the growth of host galaxy +/- SMBH

Once upon a time...

**Host Galaxy**

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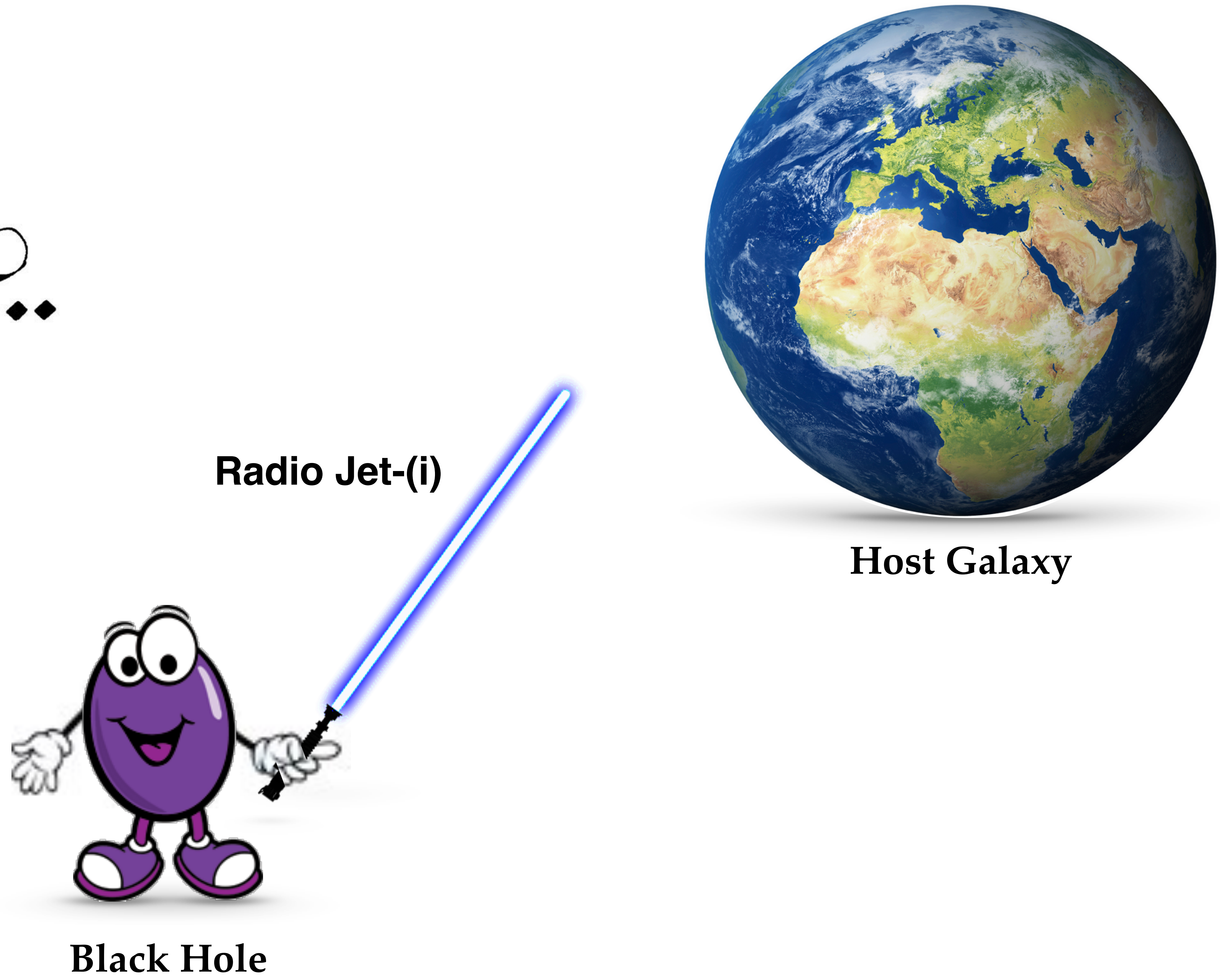
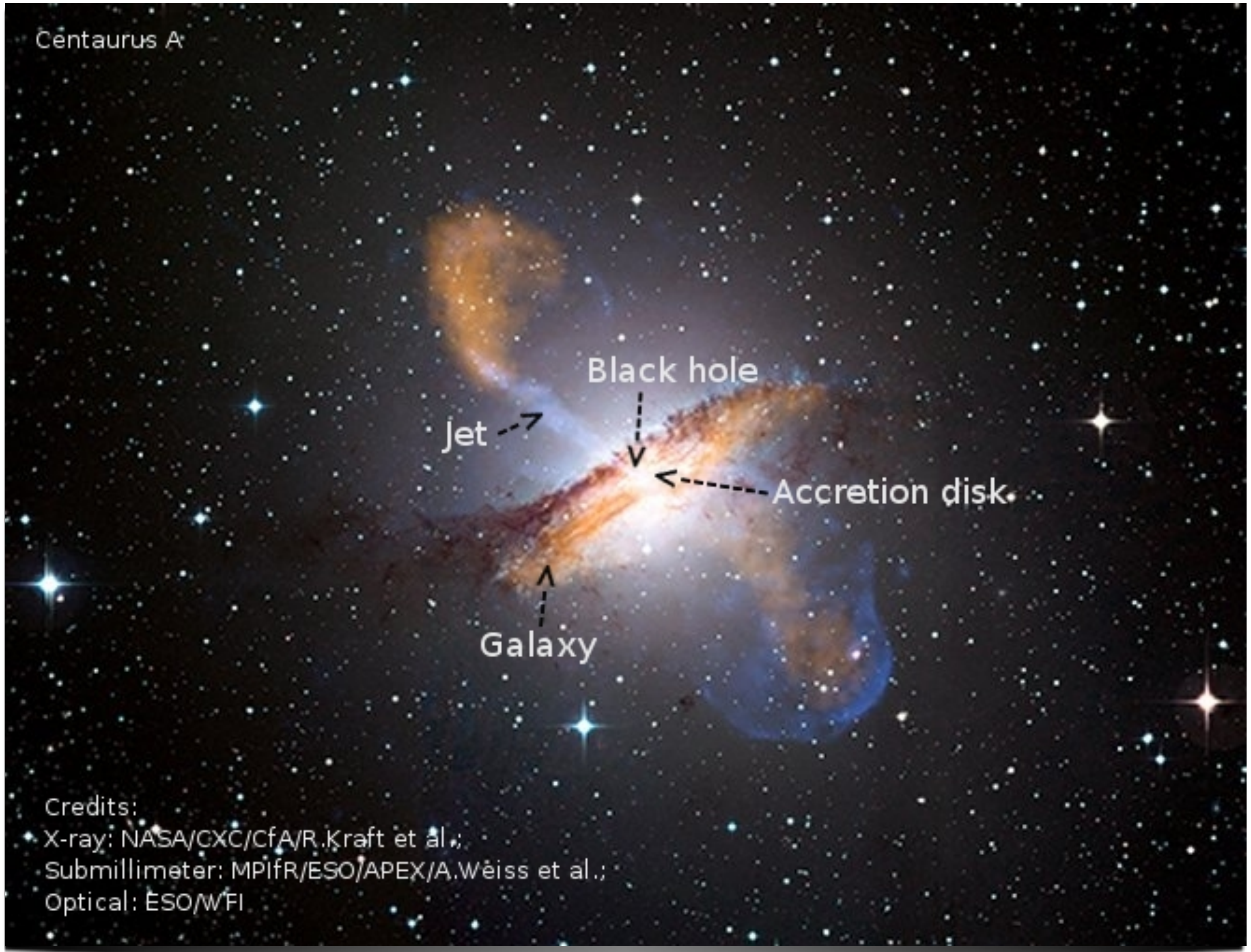
Once upon a time...



# The Importance of Radio AGN




Radio jet interact directly with the host galaxy

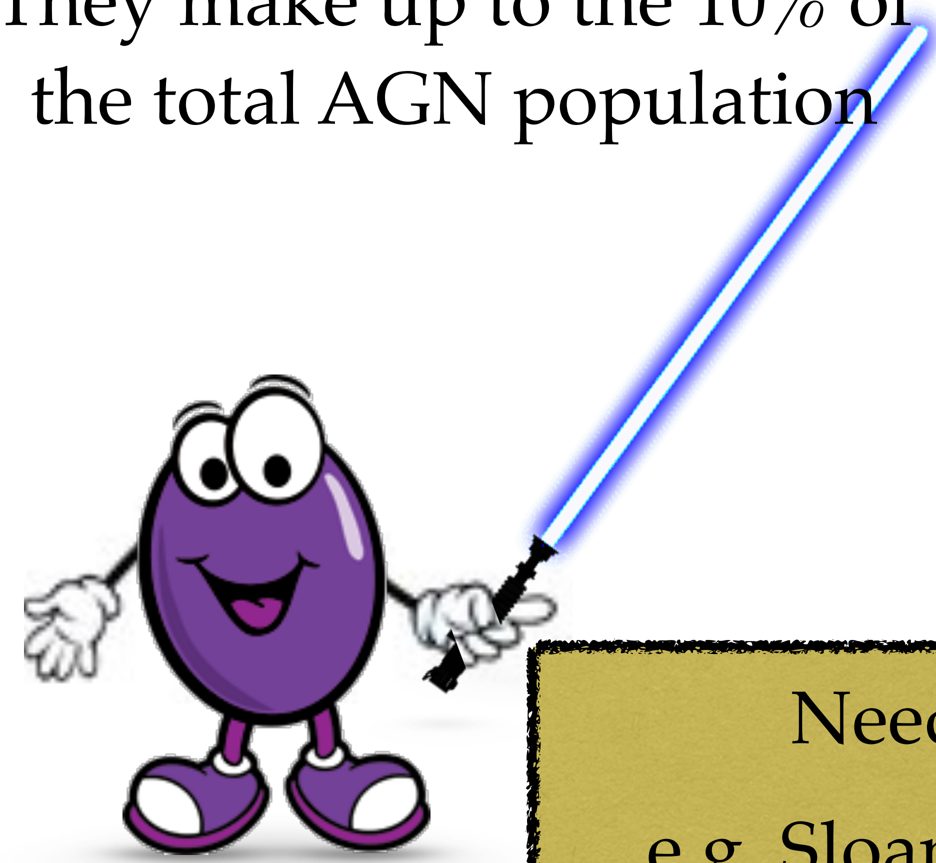
Radio galaxies make up over 30% of the massive galaxy population

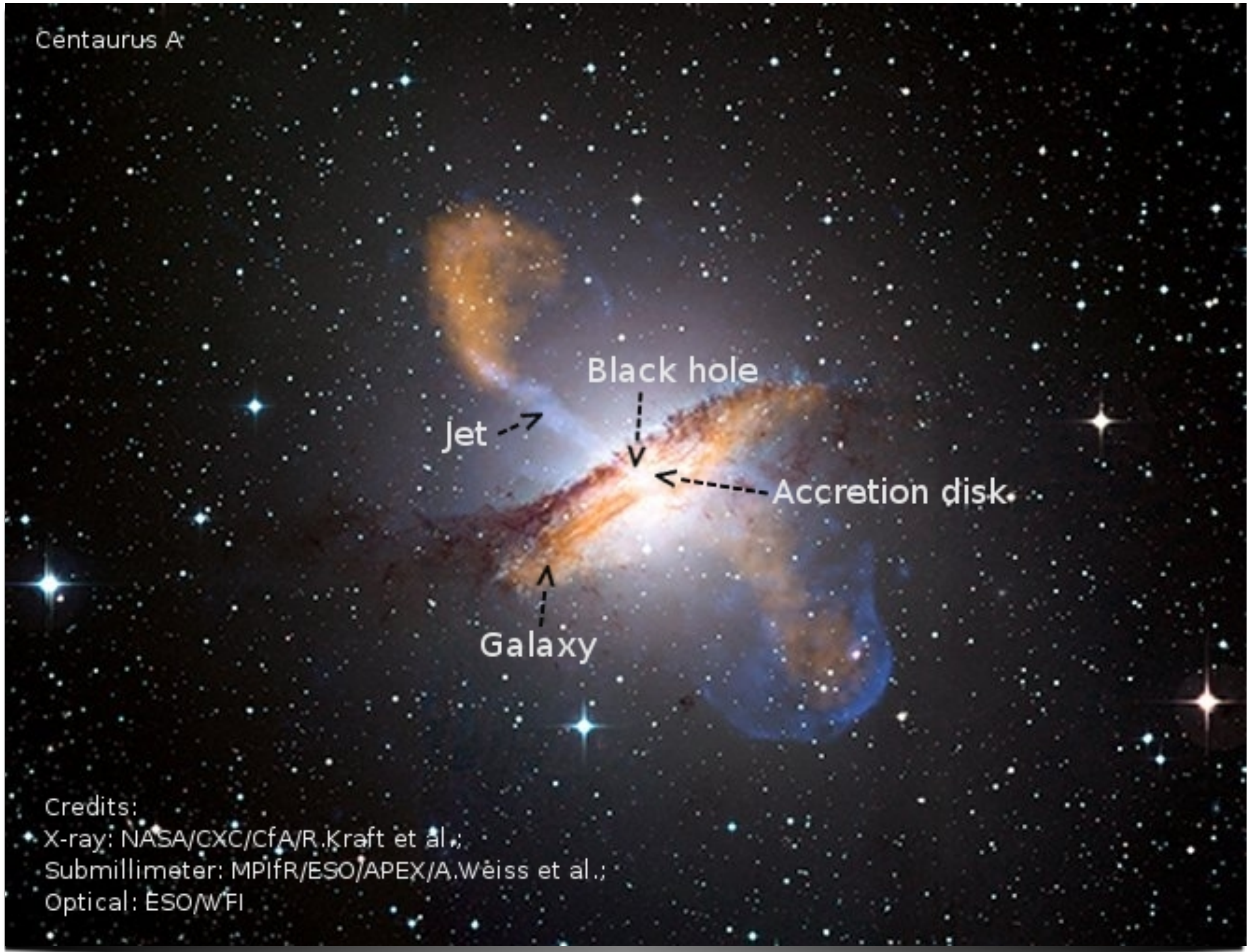
It is likely that all massive galaxies go through a radio-loud phase, as the activity is expected to be cyclical (e.g., Best et al. 2005).

# The Importance of Radio AGN

But grapes with lightsabers (just like radio AGN) are rare…

They make up to the 10% of the total AGN population

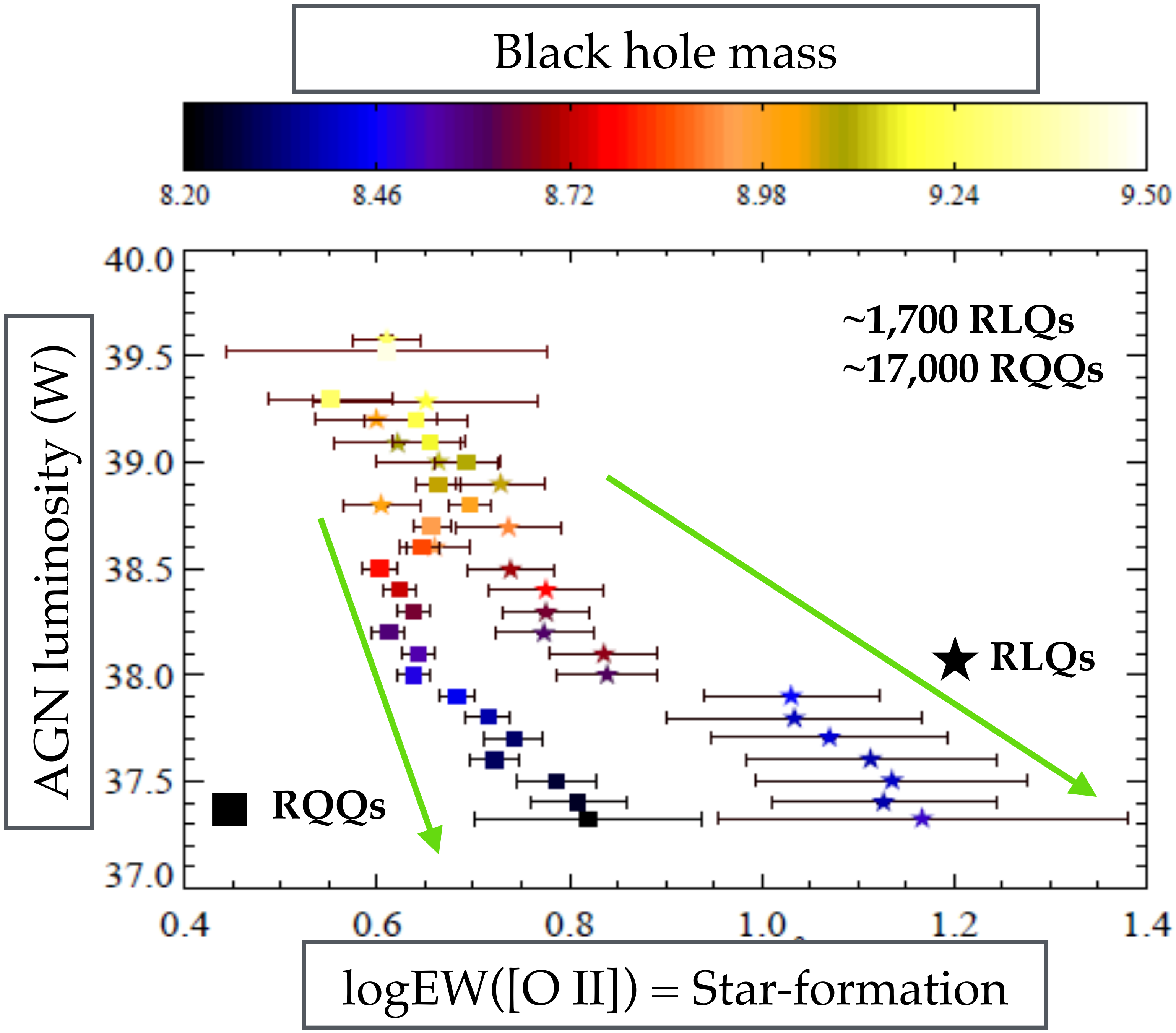





Need for wide area surveys

e.g. Sloan Digital Sky Survey (SDSS)

# Excess [OII] Emission in RLQs




Kalfountzou et al. 2012, MNRAS

## Step A: Go Wide

SDSS QSO catalogue
100,000 QSOs in 9380 sq. deg

Optical spectrum :
AGN = i-band luminosity or [OIII]
SF = [OII] emission line

Radio coverage (FIRST + NVSS)

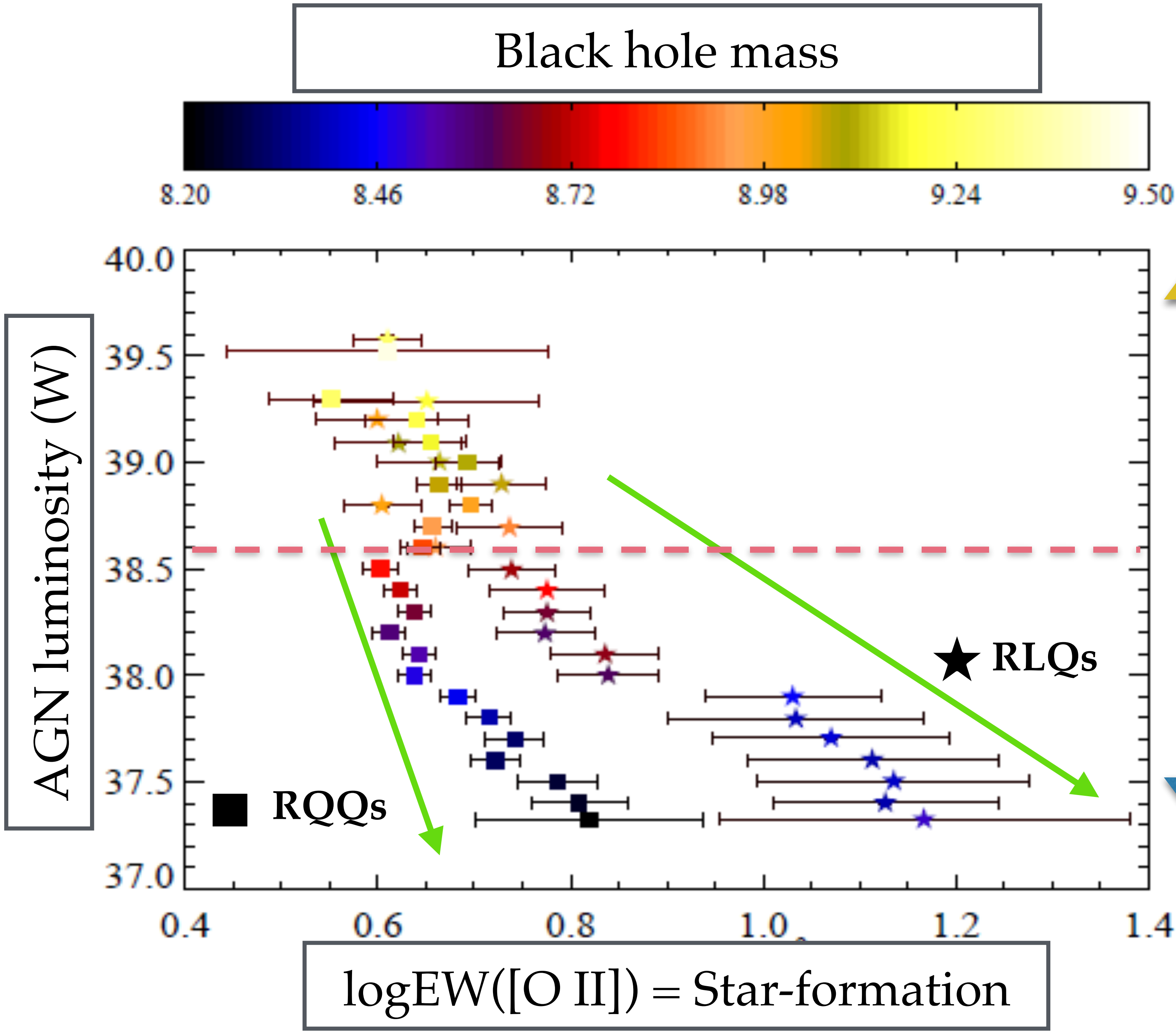
[OII] emission - AGN contamination ?

**Match samples in:**

- ✓ $z$ (< 1.4)
- ✓ Optical luminosity
- ✓ [OIII] emission

# Excess [OII] Emission in RLQs

## When? Why?




**Same [OII] emission at high AGN luminosity**

- ➢ Negative Feedback ?
- ➢ Too powerful jets ?

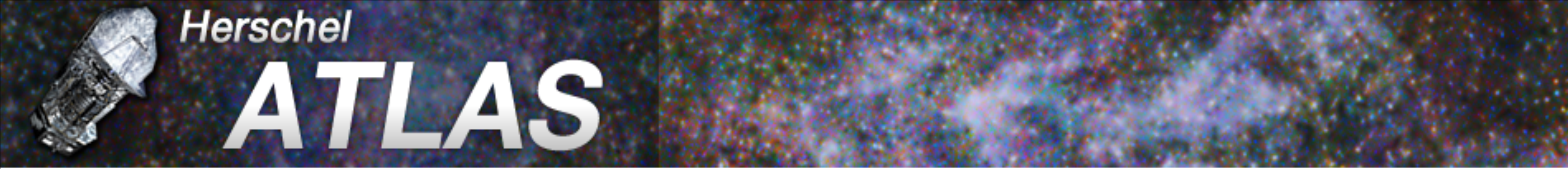
AGN luminosity limit

AGN, $M_{BH}$ or $z$ effect ??

**Excess [OII] emission at low AGN luminosity**

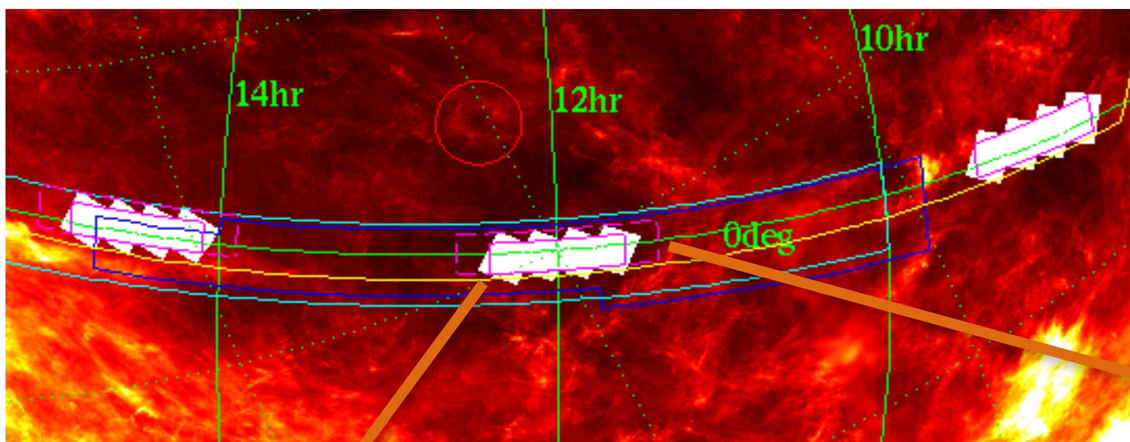
- ➢ Jets induce star-formation ?
- ➢ Alignment effect ?

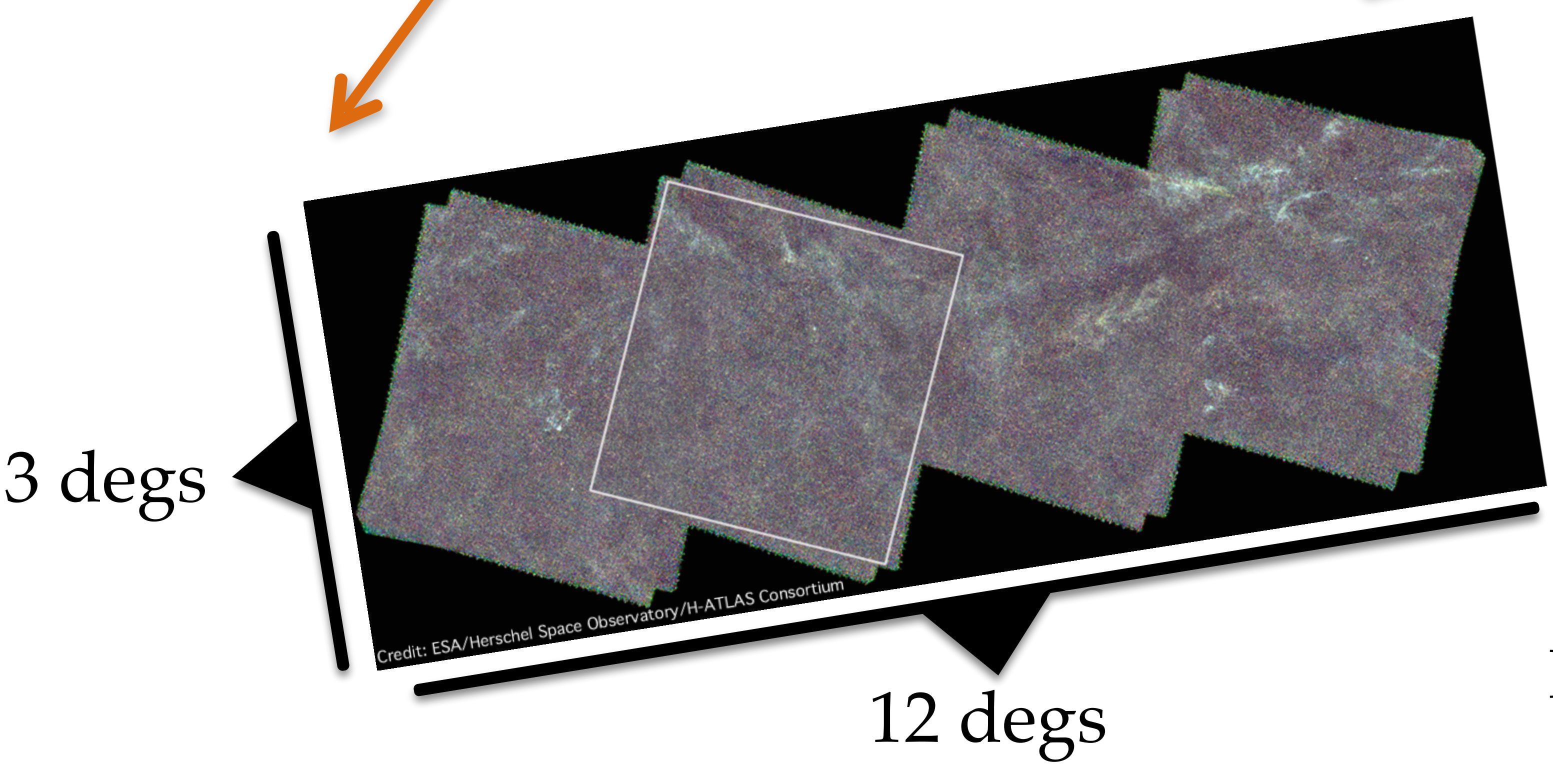
Kalfountzou et al. 2012, MNRAS




Three GAMA fields: Designed to overlap with the GAMA survey.

Total ~ 100 sq.deg




## Step B: Go far-IR

Why? Minimal AGN contamination

**AGN** & **SF** galaxies have similar SPIRE colors

**(e.g. Hatziminaoglou et al. 2010)**

H-ATLAS: SPIRE (250, 350, 500μm)

~3.5 arcsec resolution

**(Griffin et al. 2010)**

PACS (~~100~~, 160μm)

~1.5 arcsec resolution

**(Poglisch et al. 2010)**

**SDSS / H-ATLAS overlap :**

1,618 QSOs ( $z_{spec} < 5.0$ )

141 RLQs and 1,477 RQQs

Matched in *z* and optical luminosity

# LFIR Excess in RLQs

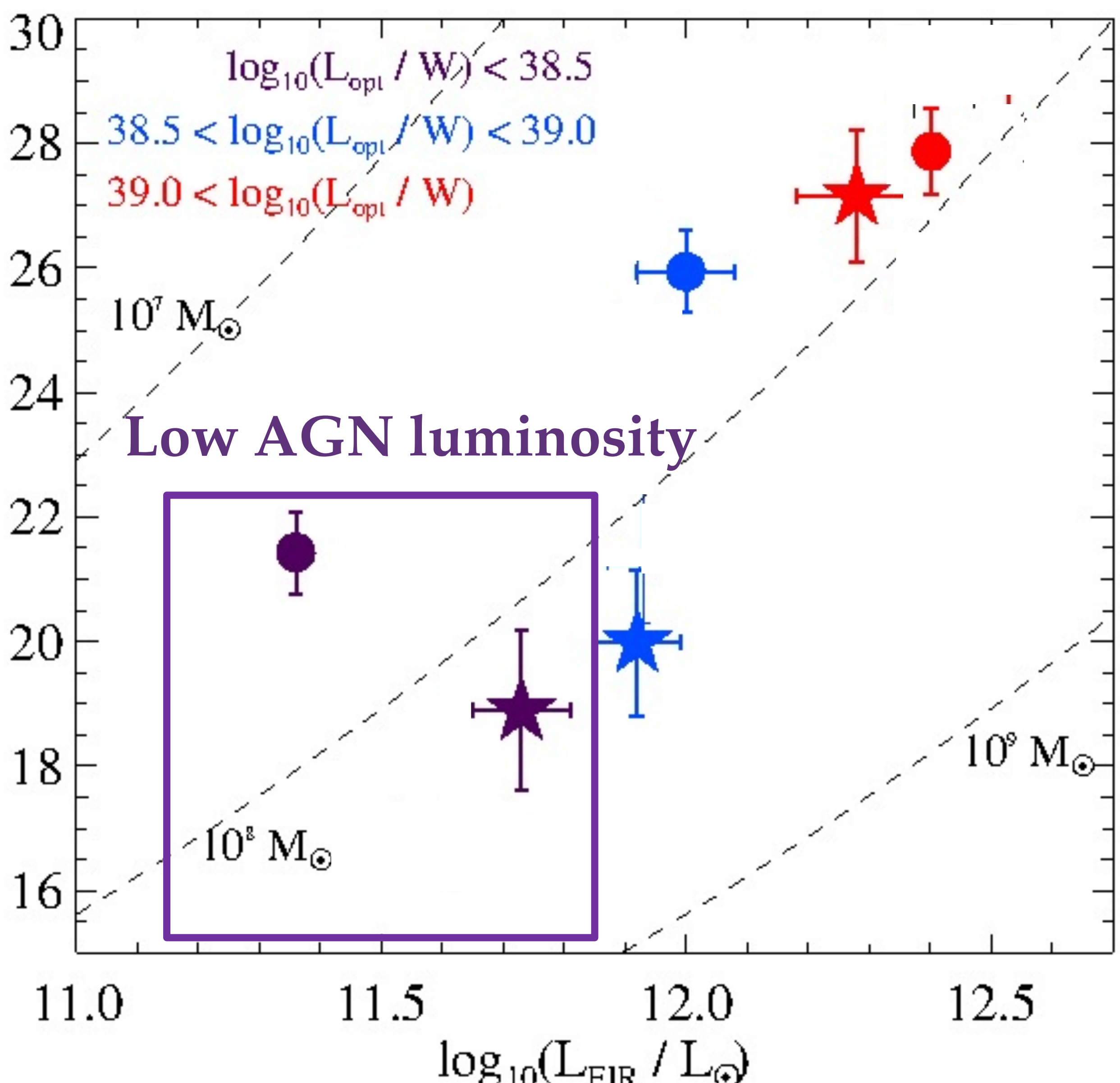
★ **RLQs**

● **RQQs**

*AGN luminosity* bins

The infrared data is stacked for all sources to take account of detected and undetected AGNs

**Dust Temperature**




**FIR luminosity = SFR**

Kalfountzou et al. 2014a, MNRAS

# LFIR Excess in RLQs

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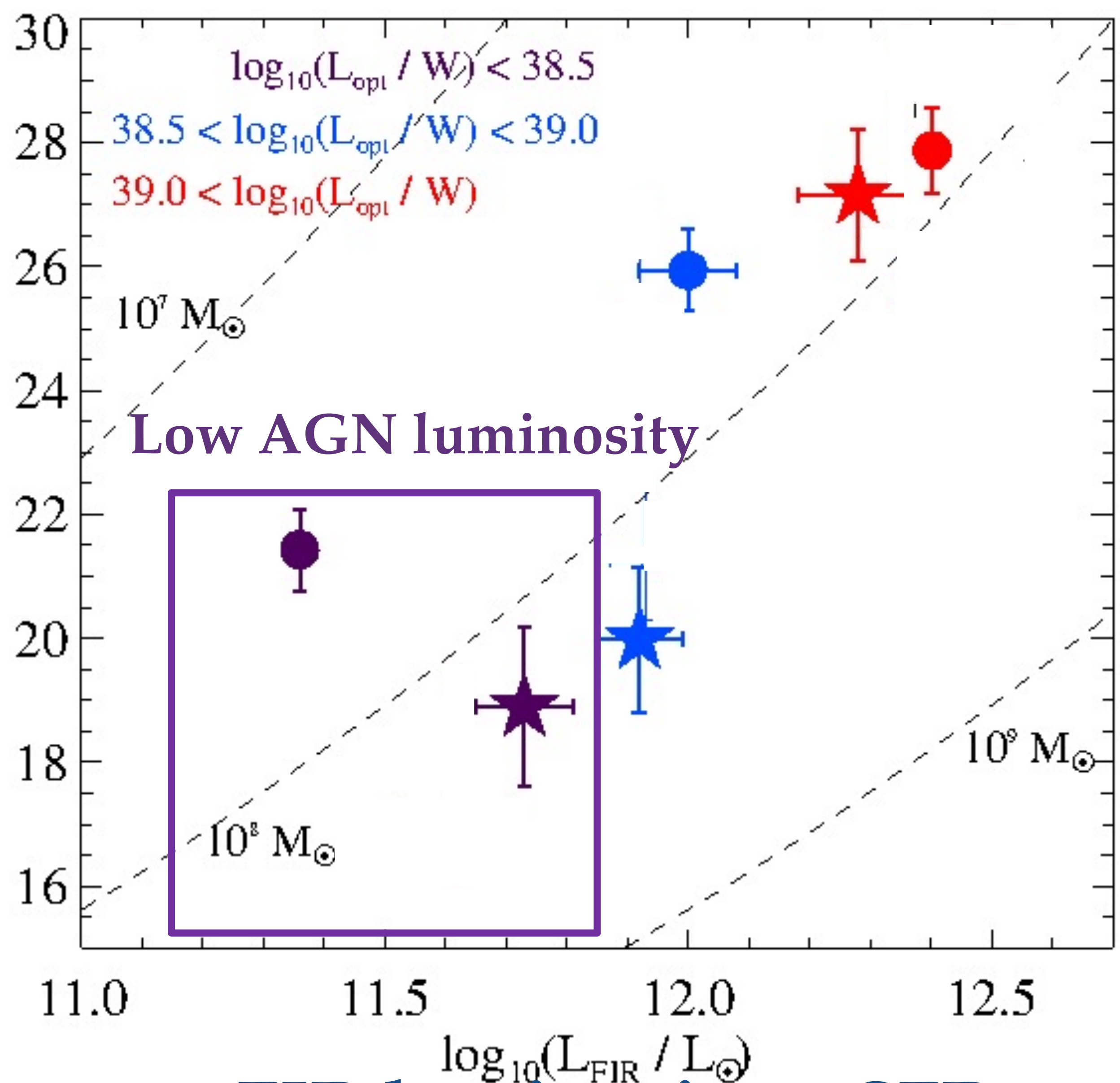



**Dust Temperature**

**FIR luminosity = SFR**

Kalfountzou et al. 2014a, MNRAS

The infrared data is stacked for all sources to take account of detected and undetected AGNs

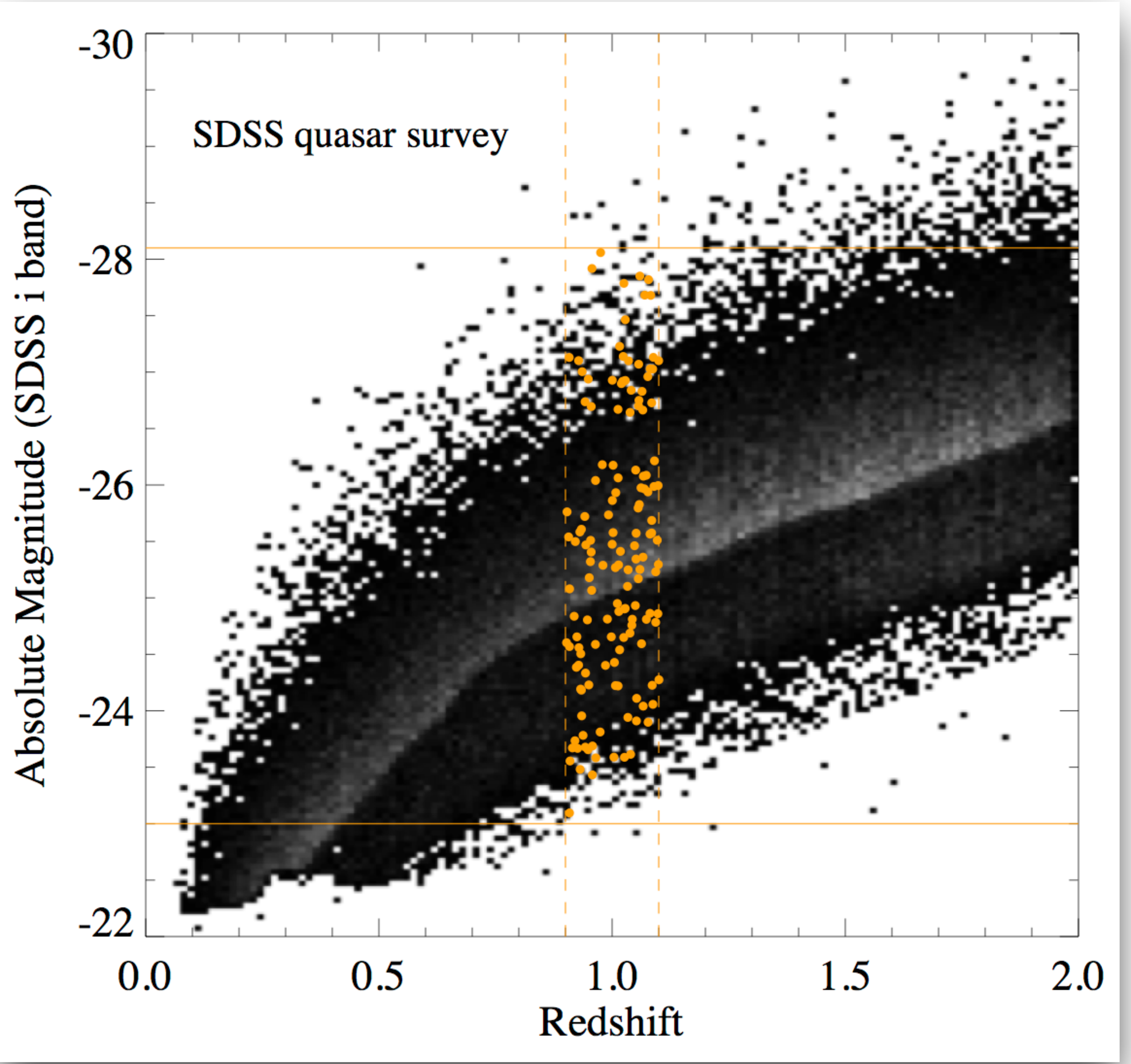
- ➢ Perfect agreement with [OII] emission excess
- ➢ Strong evidence for radio-jet positive feedback signature to the host galaxy [ **Yes, we have taken into consideration the synchrotron contamination** ]

High AGN luminosity QSOs (in our sample) are associated with higher redshift

# Star-formation of z~1 AGN

## Decompose the redshift effect

### Step C: Go single epoch




**75 RLQs**, 71 RQQs (selected from SDSS) and 27 RGs (selected from radio surveys) at the single cosmic epoch of $0.9 < z < 1.1$, spanning **5 magnitudes in optical luminosity.**

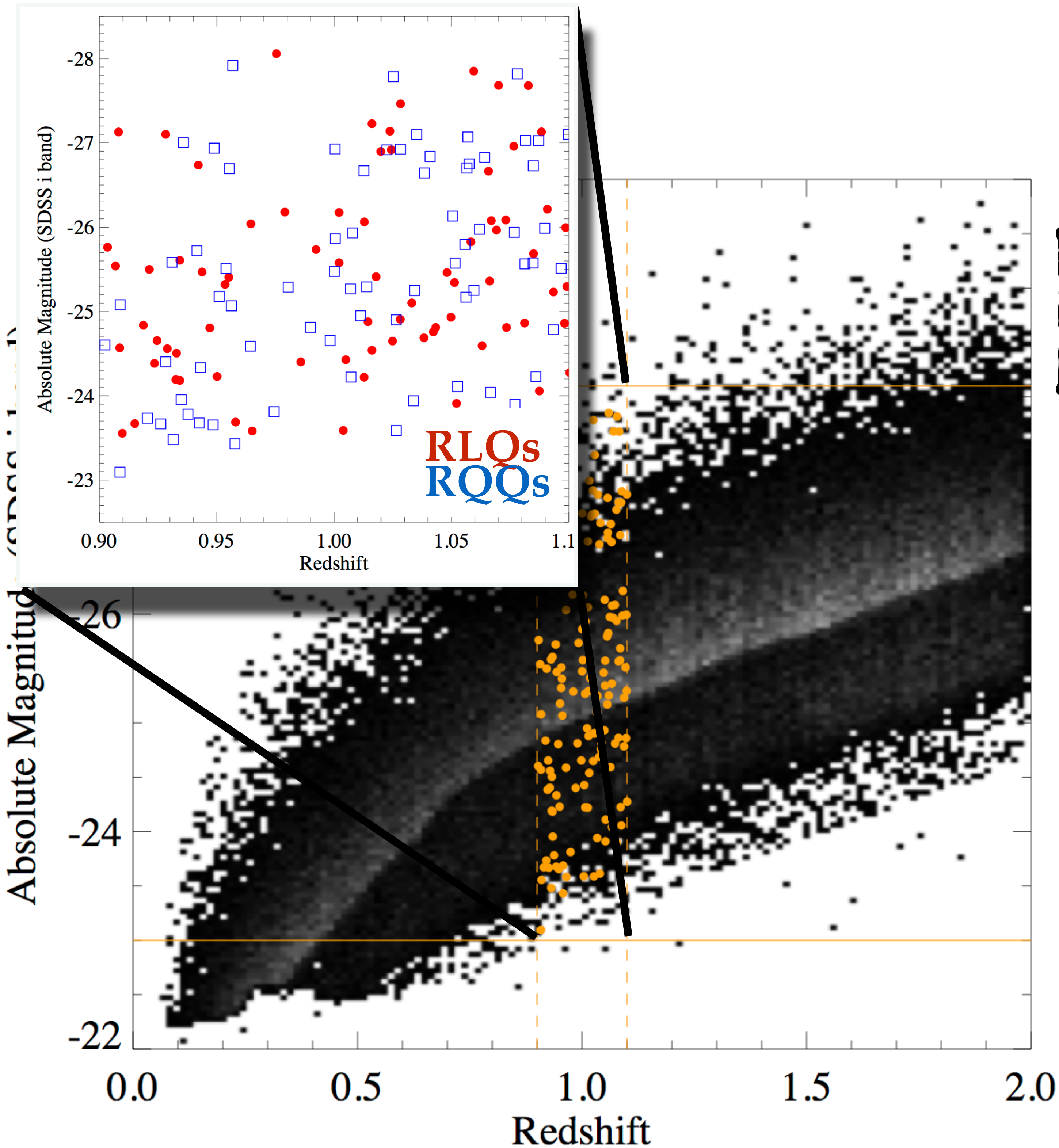
*Herschel*-SPIRE & PACS, XMM-Newton, SWIFT, Spitzer, UKIRT, GMRT, SMA (PIs: Stevens, Jarvis, Hardcastle, Kalfountzou, Page)

**Next paper:** RLQs and RQQs templates, update Elvis+1994 QSO templates

**Kalfountzou et al. 2015 submitted**

# Star-formation of z~1 AGN

## Decompose the redshift effect



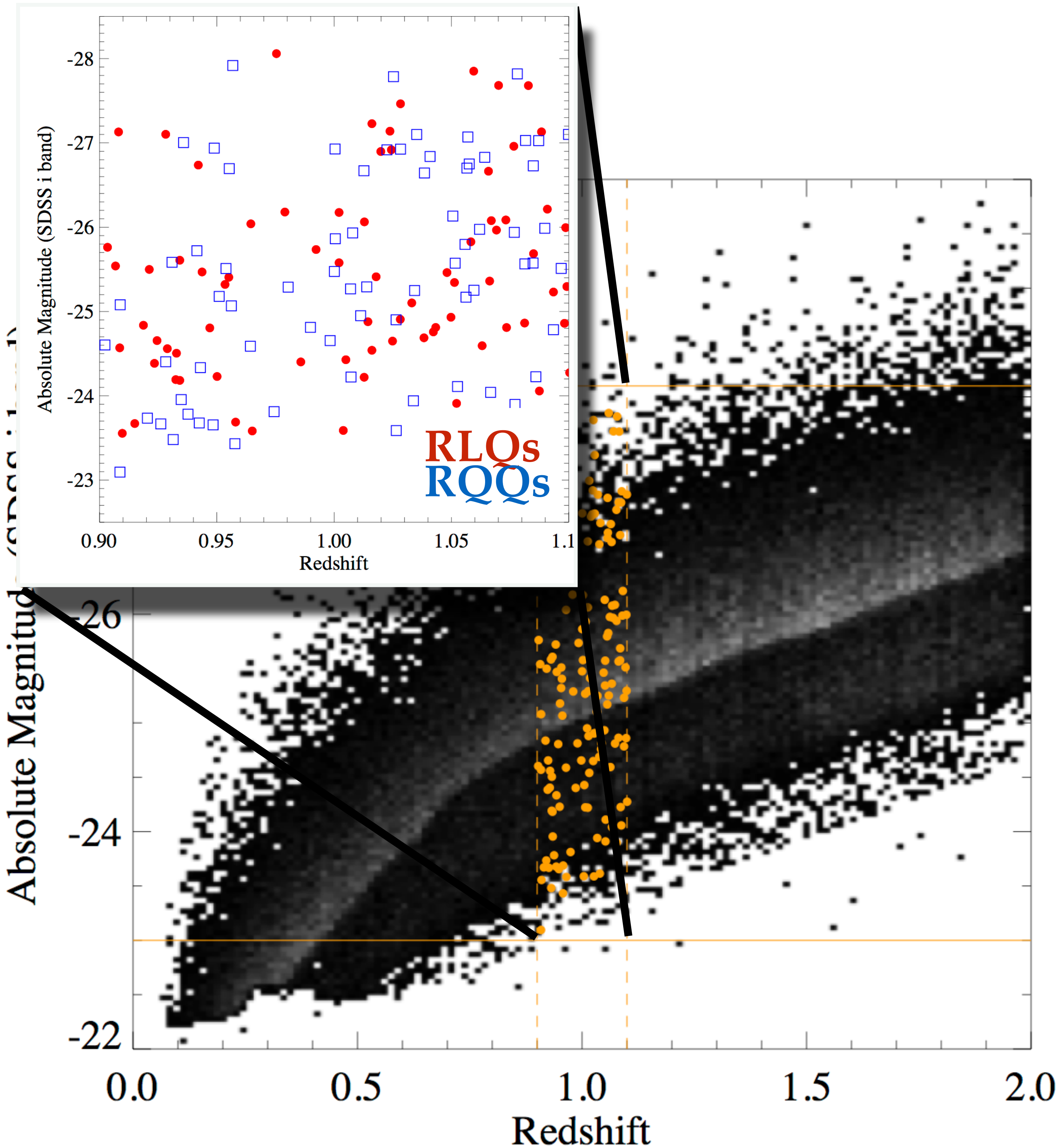

**Perfect QSO comparison sample to future works at different redshifts**

The minimum redshift at which we have a large enough sample of high luminosity quasars with which to compare to the bright quasars found at higher redshifts.

Close to the peak of the AGN luminosity density in the Universe (e.g. Barger et al. 2005; Hasinger et al. 2005).

# Star-formation of z~1 AGN

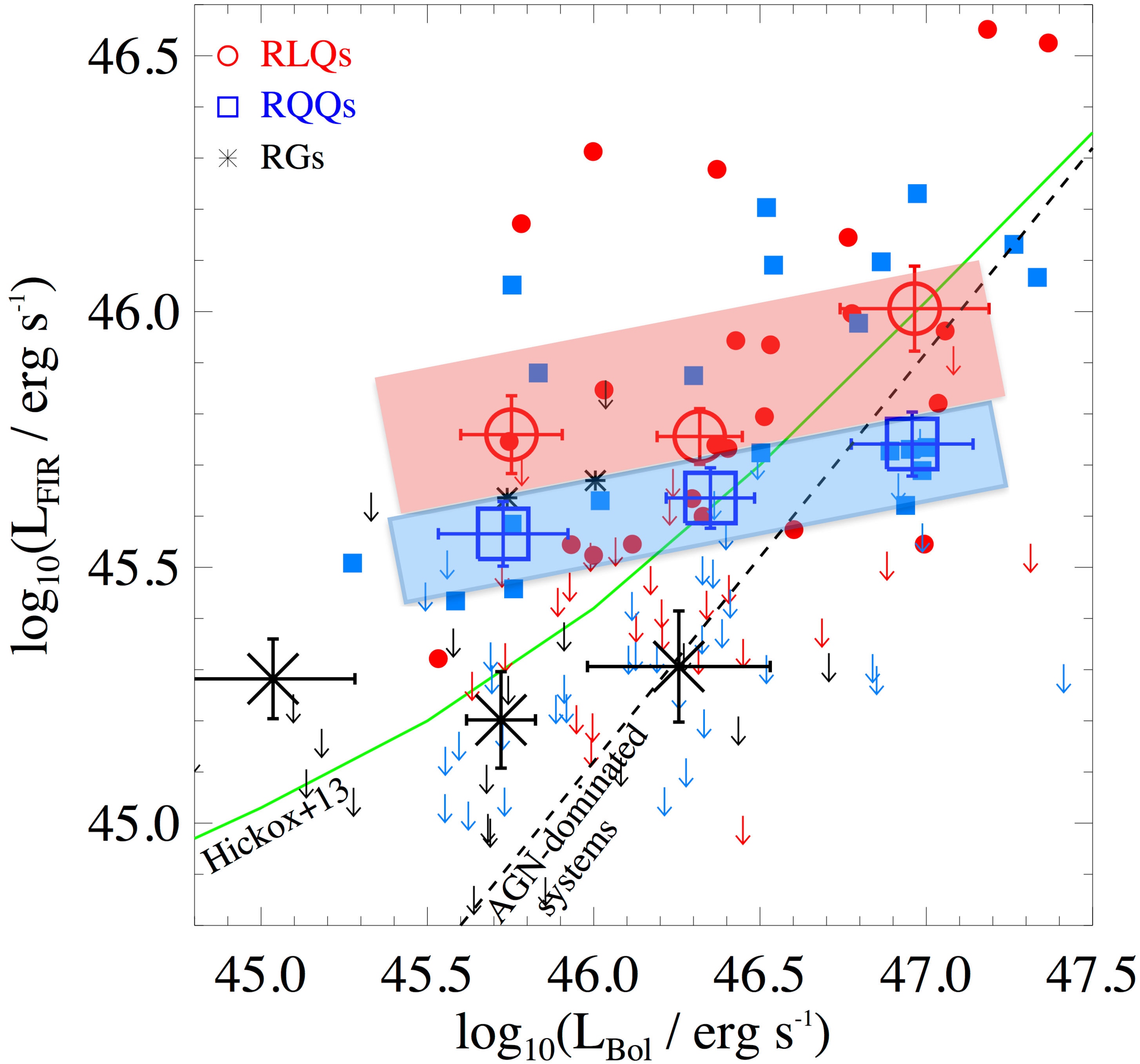
## Decompose the redshift effect




### The Questions:

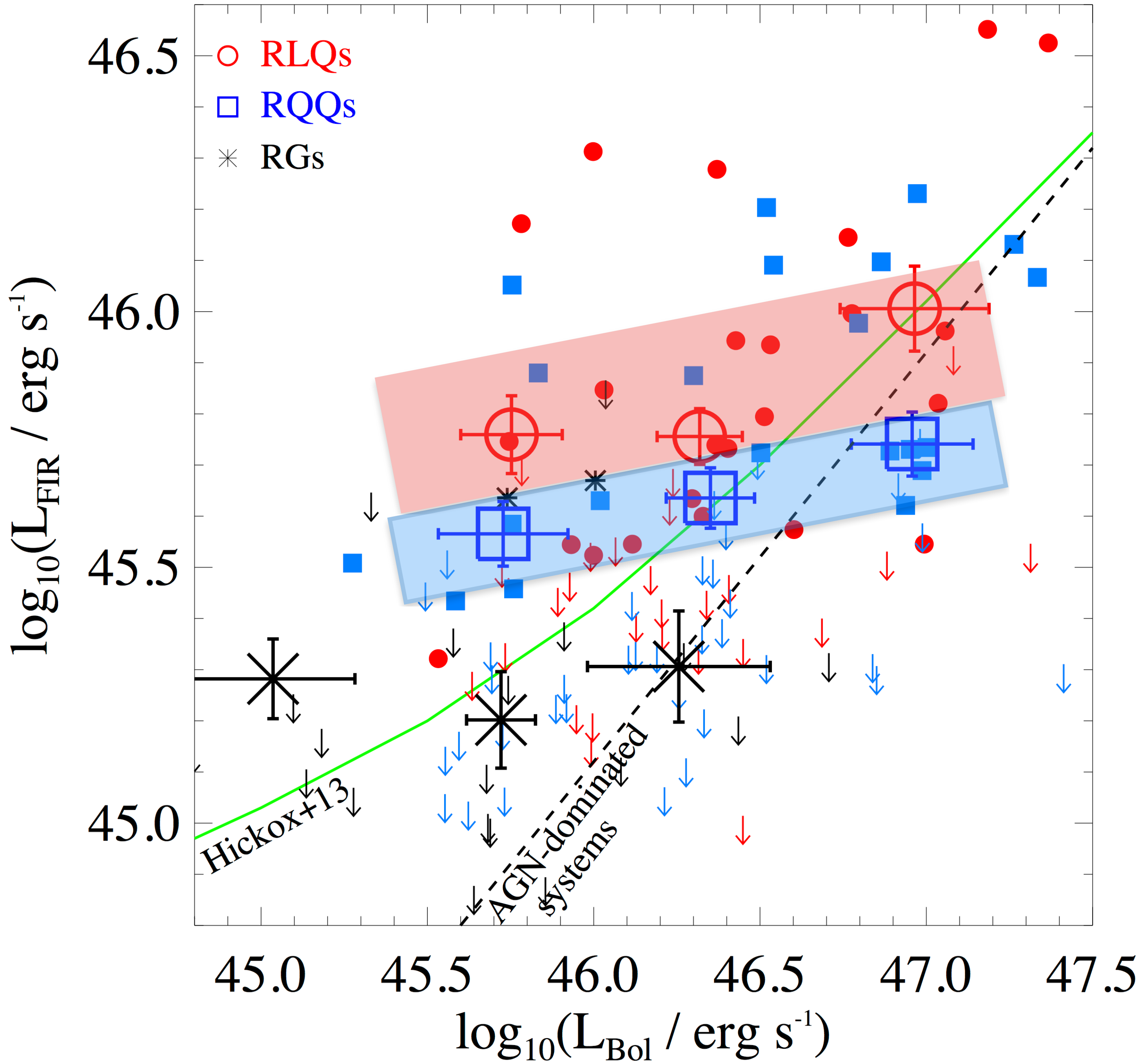
1. How SFR depends on **radio-loudness** (see RLQs vs. RQQs)
2. How SFR depends on **orientation** (see RLQs vs. RGs)
3. How SFR depends on **AGN luminosity** (see RQQs)

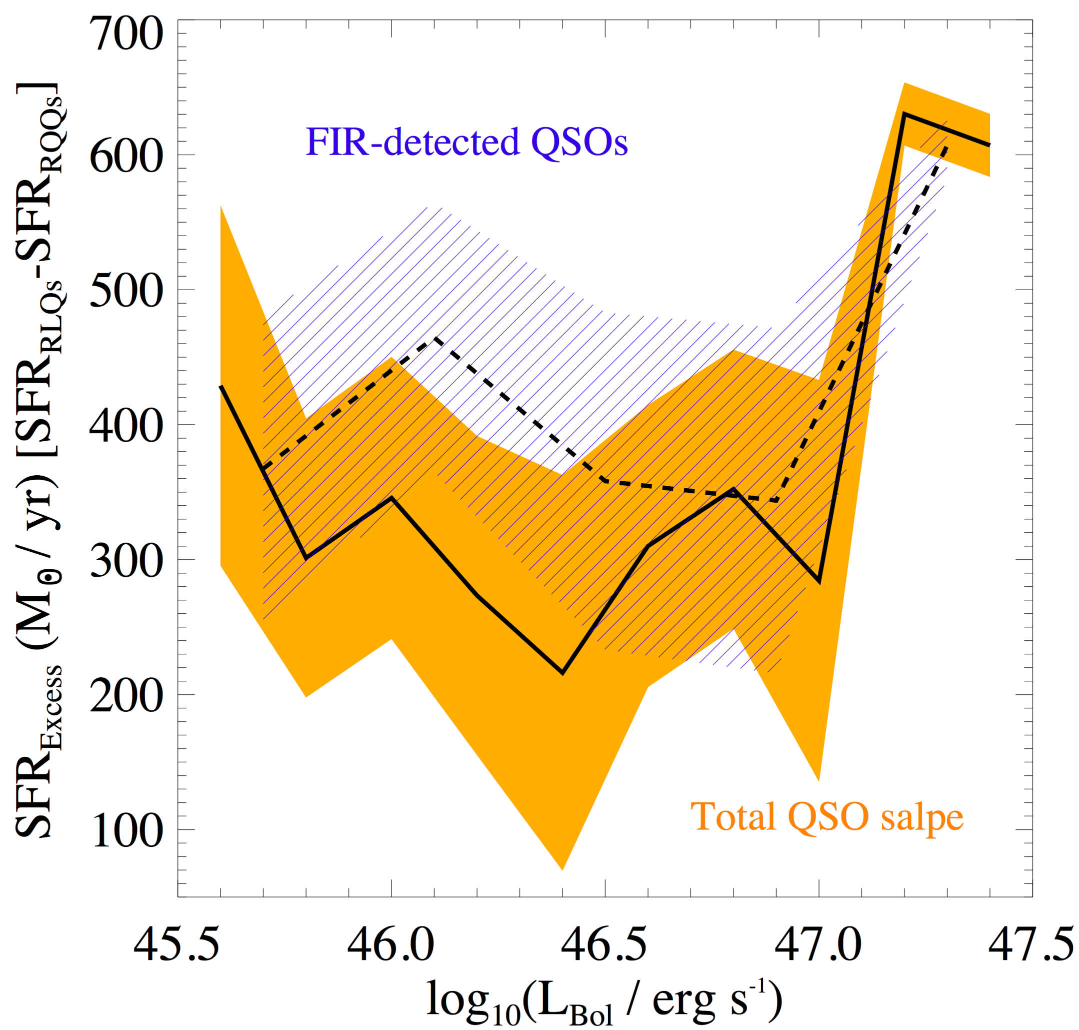
# Star-Formation Dependance on Radio-loudness




**Kalfountzou et al. 2015 submitted**

# Star-Formation Dependance on Radio-loudness




Radio-jets enhance star-formation in their host galaxies

No dependance on AGN activity -> evolution effect (see our previous results)

**Kalfountzou et al. 2015 submitted**

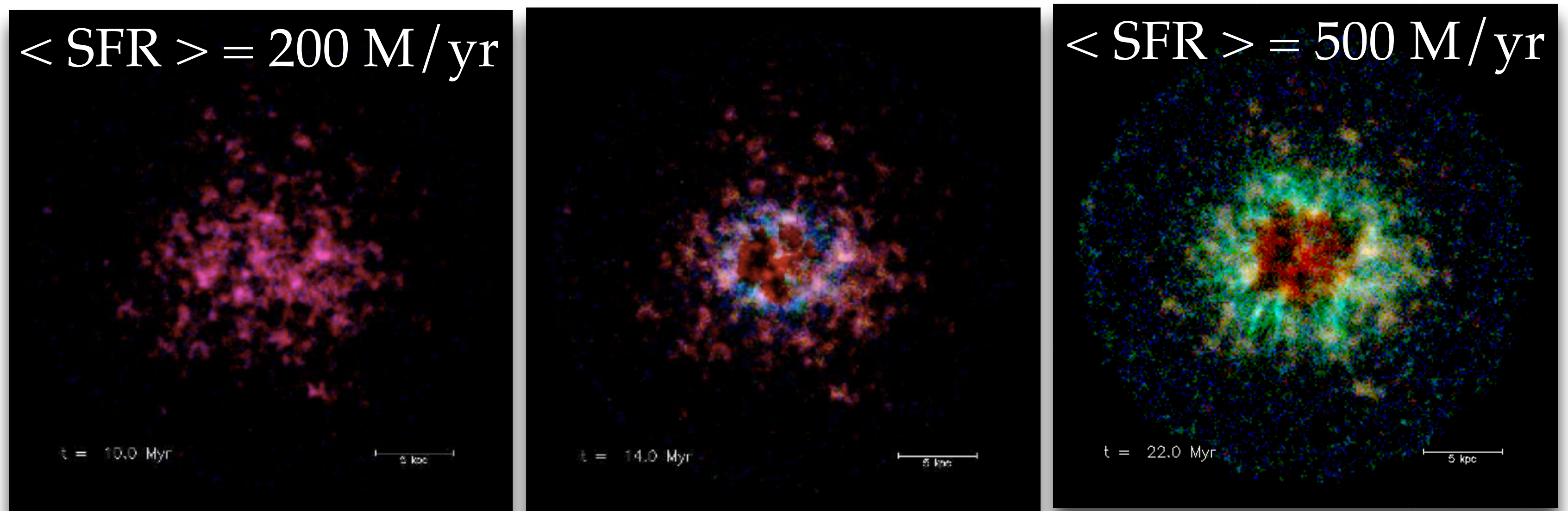
# Our (Preferred) Explanation

Radio - jet turns on

ring- or disc-shaped population of young stars

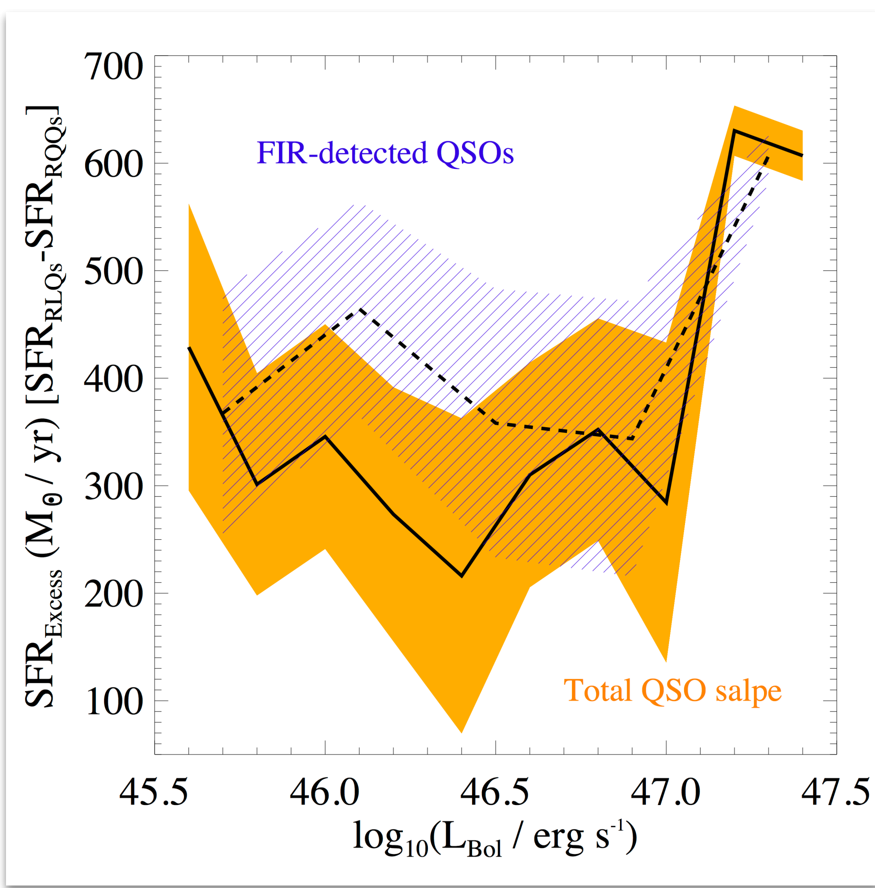
## Simulations

for gas-rich AGN




t = 10.0 Myr    t = 14.0 Myr    t = 22.0 Myr

**Gaibler et al. 2012**




Simulations of the interaction of a powerful AGN jet with the massive gaseous disc of a high-redshift galaxy

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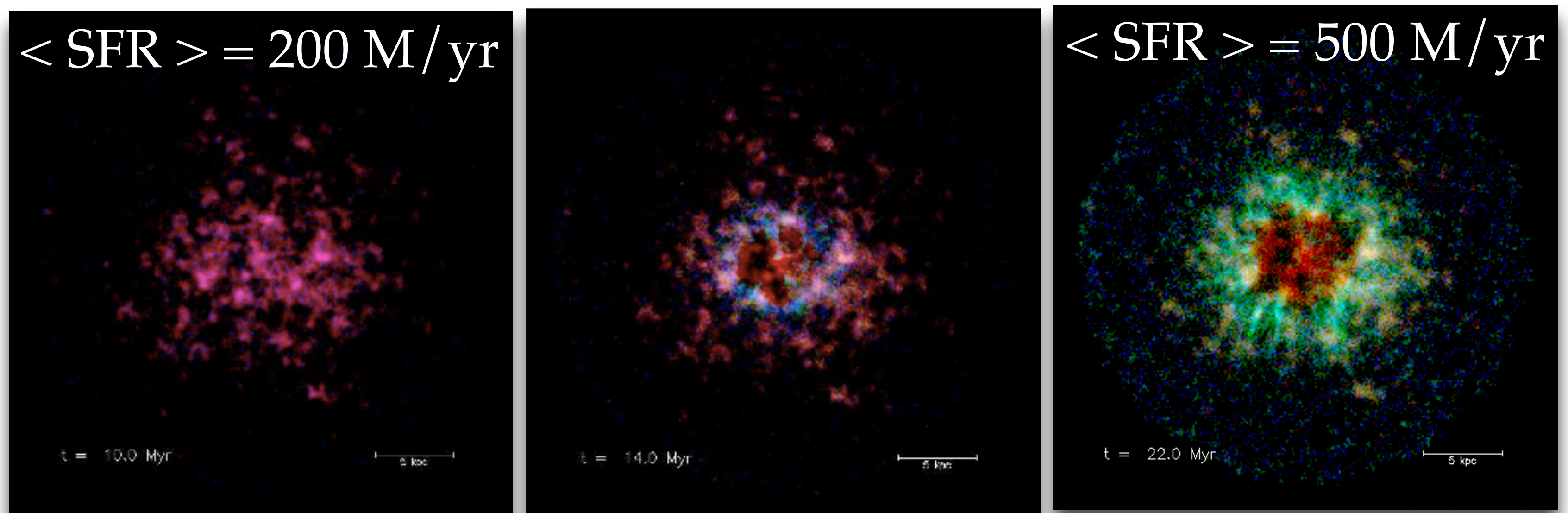


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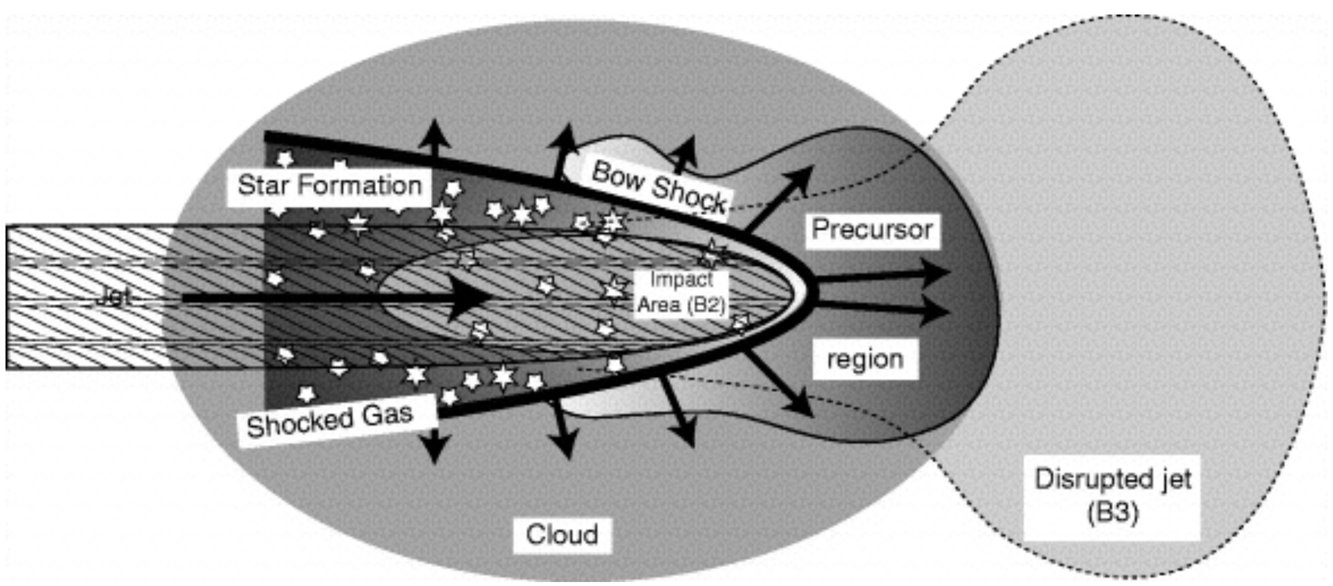
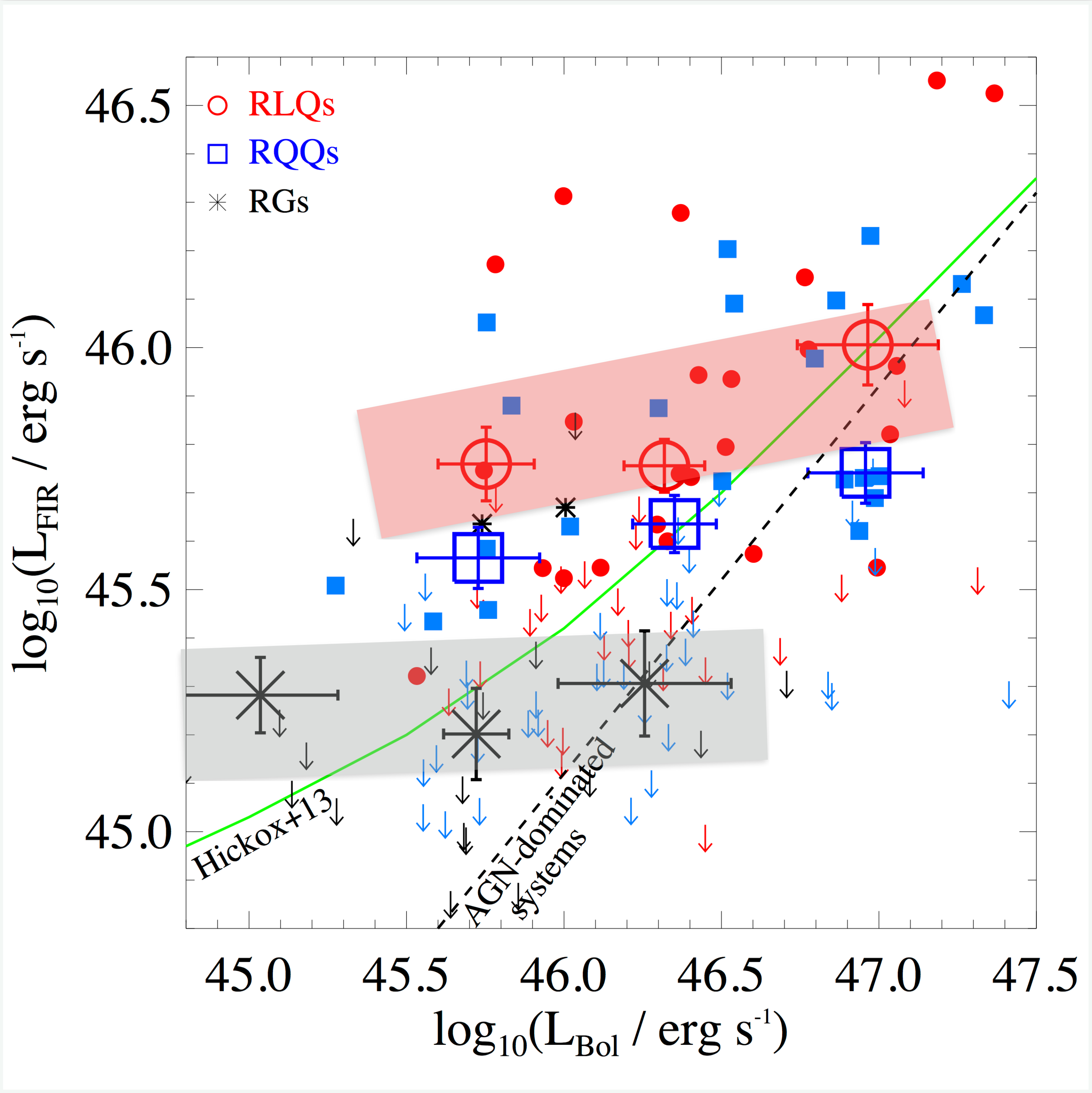



Van Breugel et al. 2000

Simulations of the interaction of a powerful AGN jet with the massive gaseous disc of a high-redshift galaxy

**How**? jet shocks gas reservoirs and thereby induces shocks and turbulence → accelerated clumping of gas → **Positive feedback**

# Star-Formation Dependance on Orientation



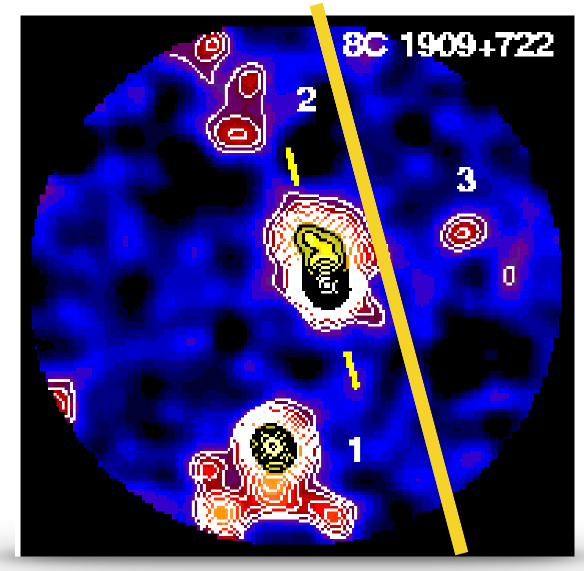

If RLQs and RGs are the same objects, why RGs have much lower SFR for the same BH mass?

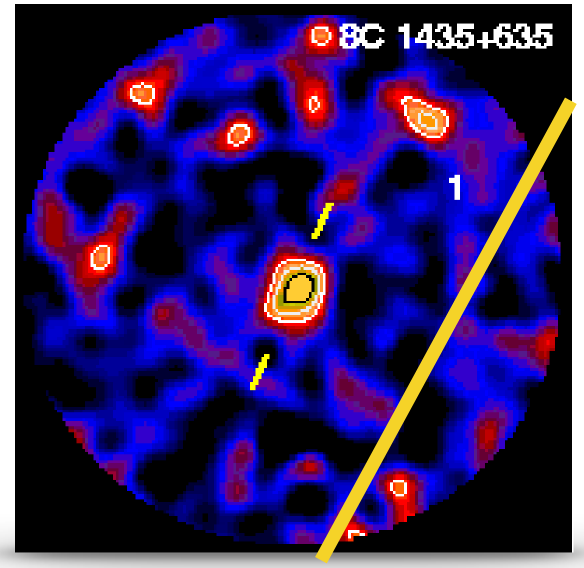
Only 2/27 RGs are detected!

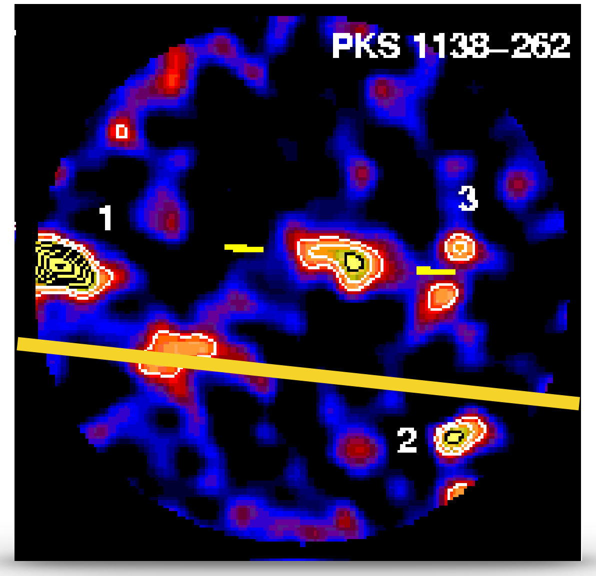
Unified model doesn't predict these differences

Similar results even if we match the samples into radio-power

# Unified model vs. Selection




Stevens et al. 2003, Nature

Radio galaxies

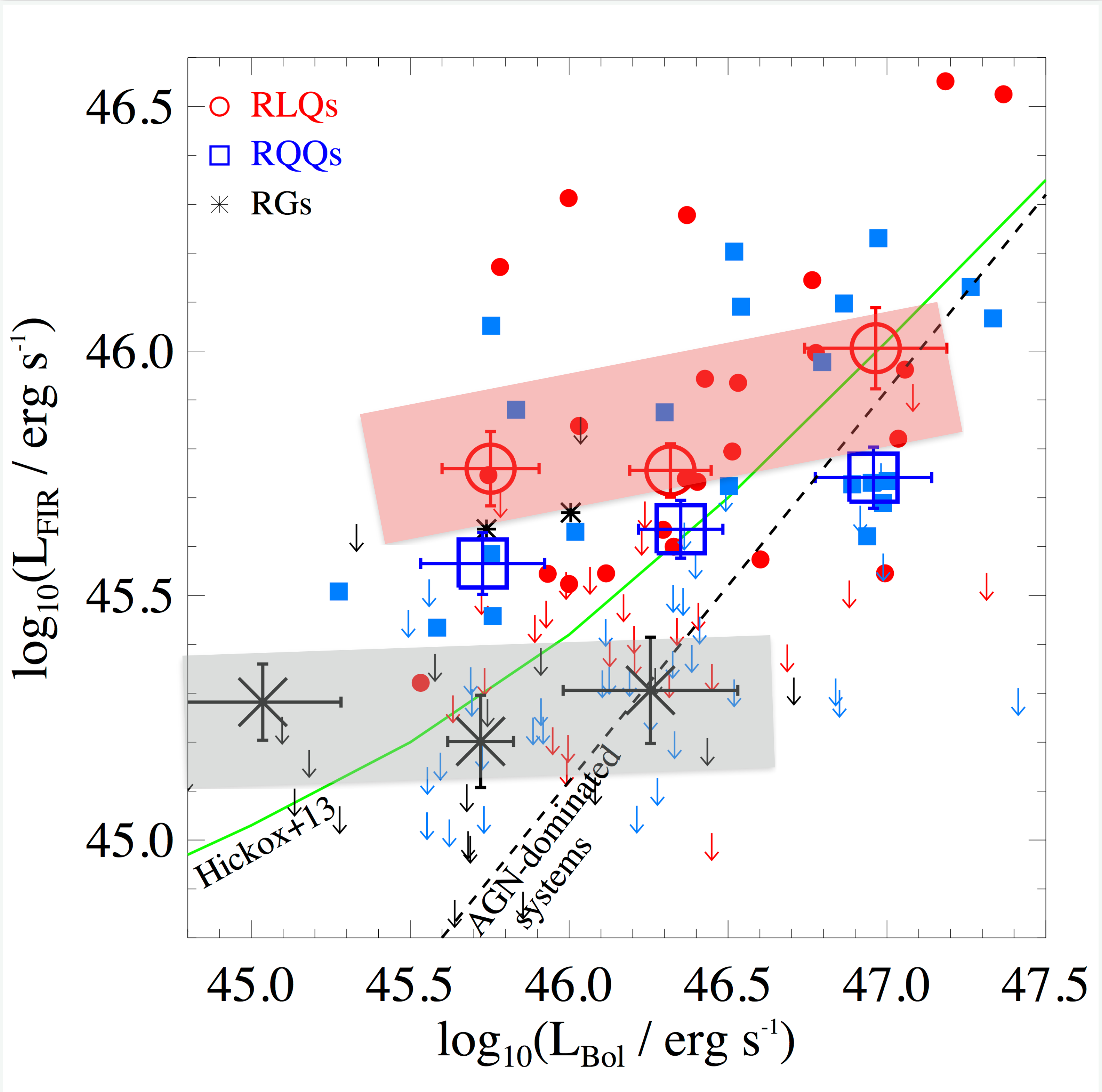
Deep submm mapping with SCUBA

**RGs are selected from radio surveys -> the most radio luminous AGNs**

**rich clusters which peak at higher redshifts**

Jets aligned with the **densest regions of gas**, thereby producing very effective working surfaces and the brightest hot spots. Such a selection effect has been suggested before to explain apparent large-scale optical-radio alignment effects at lower redshift

# Radio Jets Efficiency Evolution




**Kalfountzou et al. 2015 submitted**

Most radio power AGN have formed their stars at earlier Universe

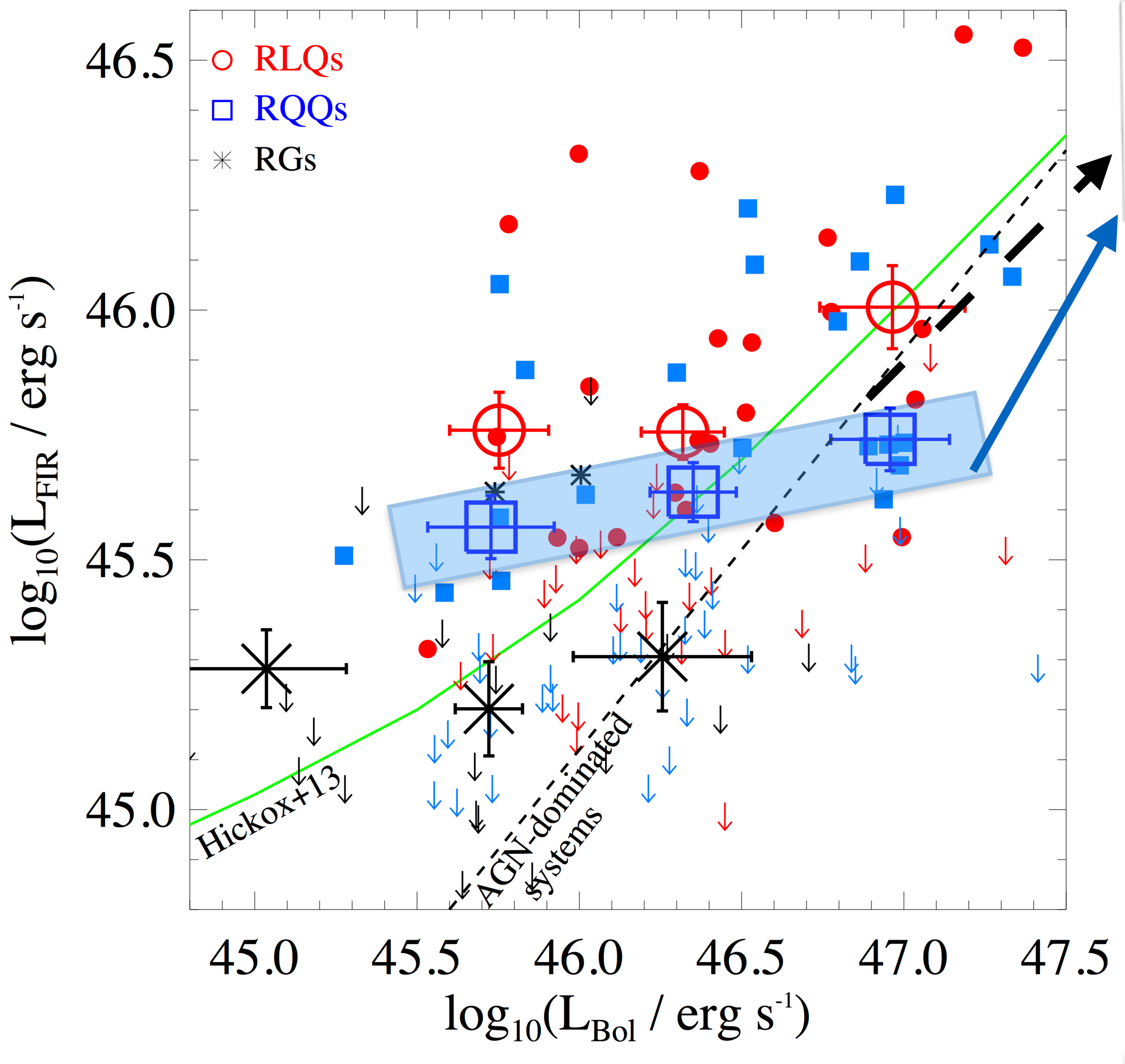
Positive radio feedback seems to become efficient at later epochs

Association with gas availability?

Need for comparison with high-z samples

# Is There Evidence of correlated BH and Galaxy Growth?

What the radio-quiet quasars say?




Much flatter correlation than expected from AGN-dominated systems (e.g. Netzer et al.2009)

But NO evidence for star-formation suppress in our data [~40% detection rate]

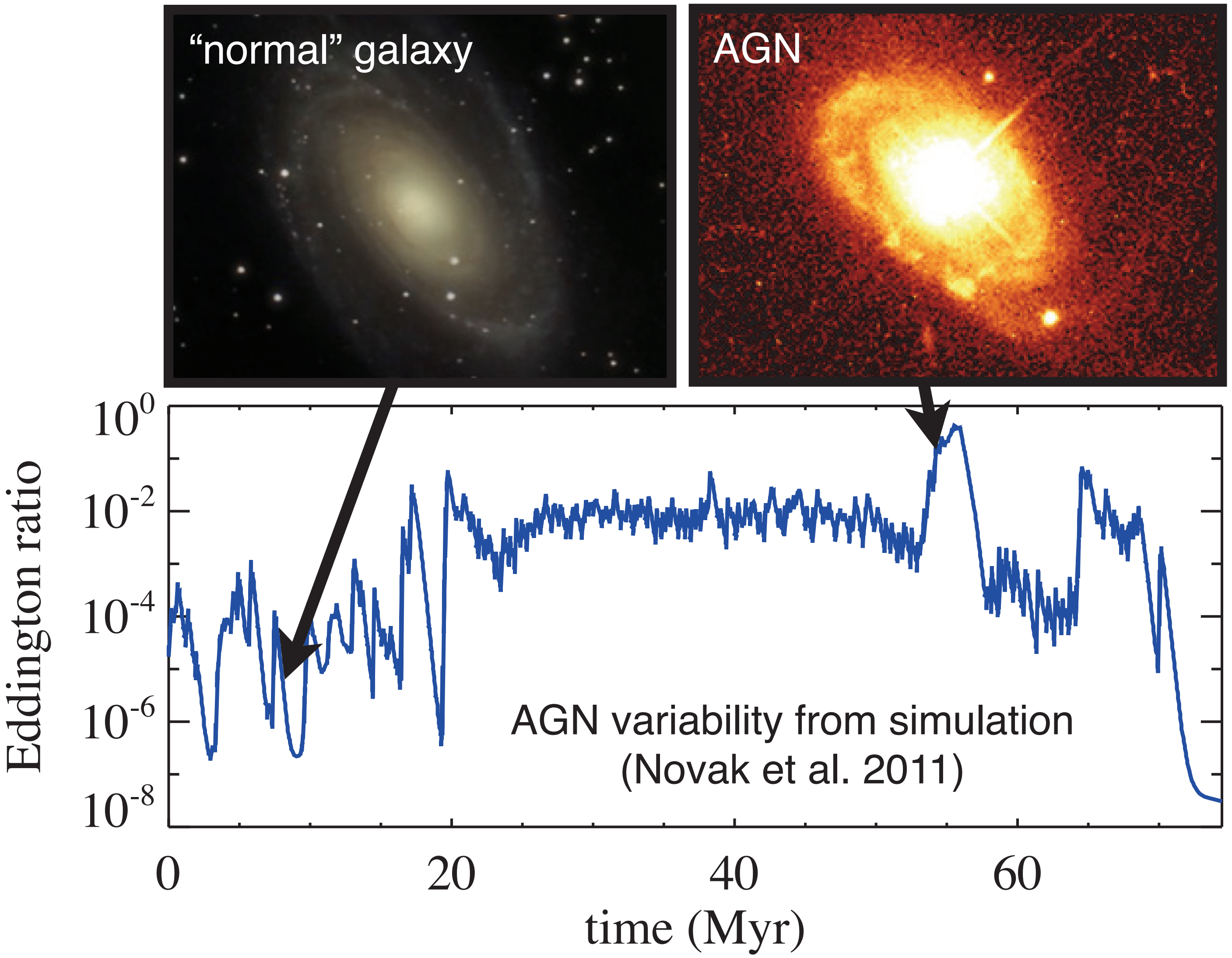
(see **Page et al. 2012**; AGN negative feedback)

**Kalfountzou et al. 2015 submitted**

# No Correlation of Hidden Correlation?

**Lifetime of star formation**: ~$10^8$ years and due to the large size of star-forming regions, star formation will be comparatively stable on timescales of >$10^6$ years

A significant caveat in the interpretation of this data is that AGNs vary on short timescales while galaxies (or star formation) does not!

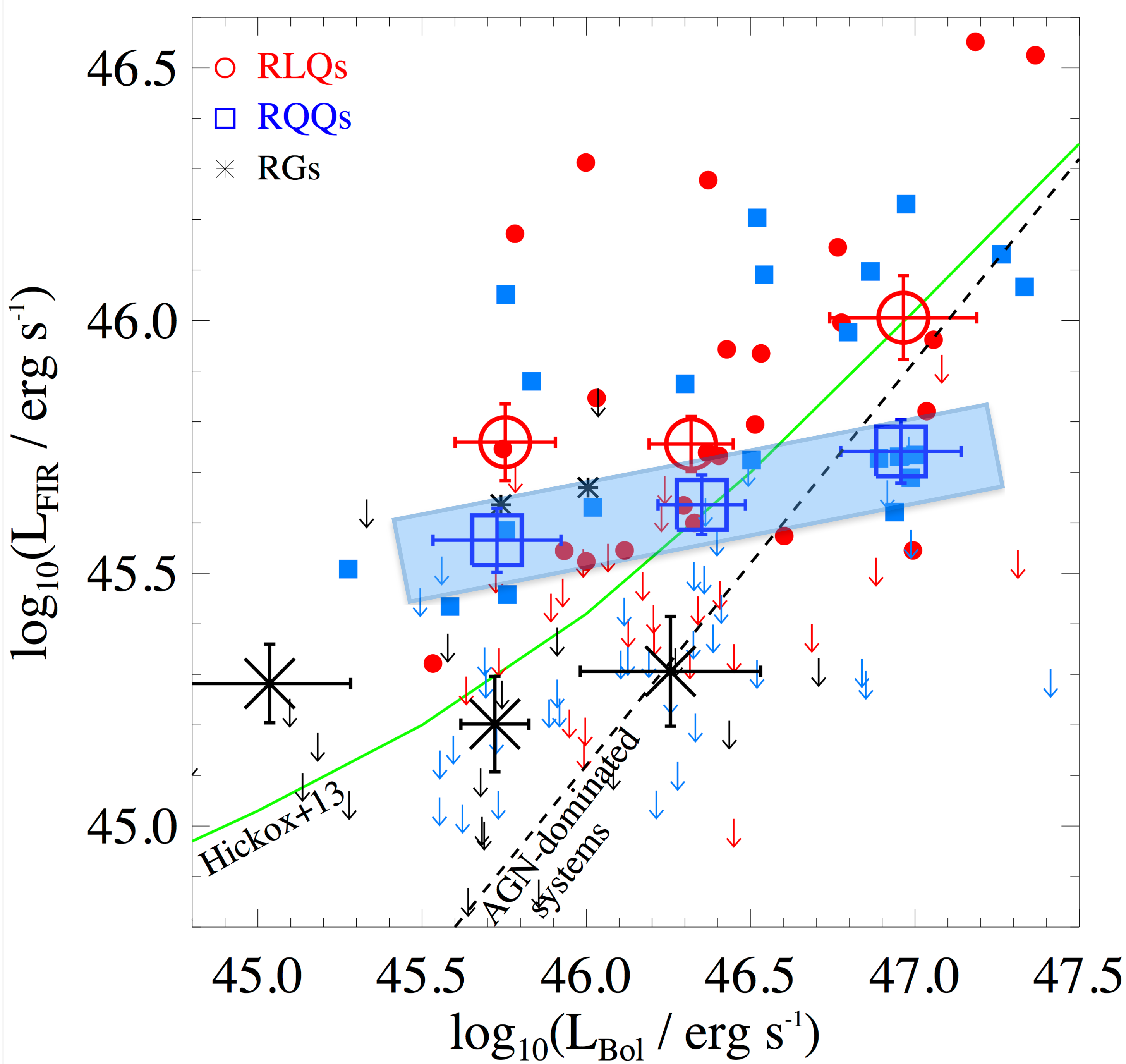



**Lifetime of AGNs**: ~$10^6$ years but AGNs can vary in luminosity on timescales of days and large-scale accretion disc timescales will be on timescales of centuries

**What does this mean?**

AGN variability can mask the true underlying correlation

# No Correlation of Hidden Correlation?




**Kalfountzou et al. 2015 submitted**

Empirical toy-model assumes that SFR is correlated to the LAGN when averaged over timescales of the order of 100Myr. **(Hickox et al. 2013)**

Efficiently predicts the flat correlation found for low luminosity X-ray AGN **(e.g. Rosario et al. 2012)**

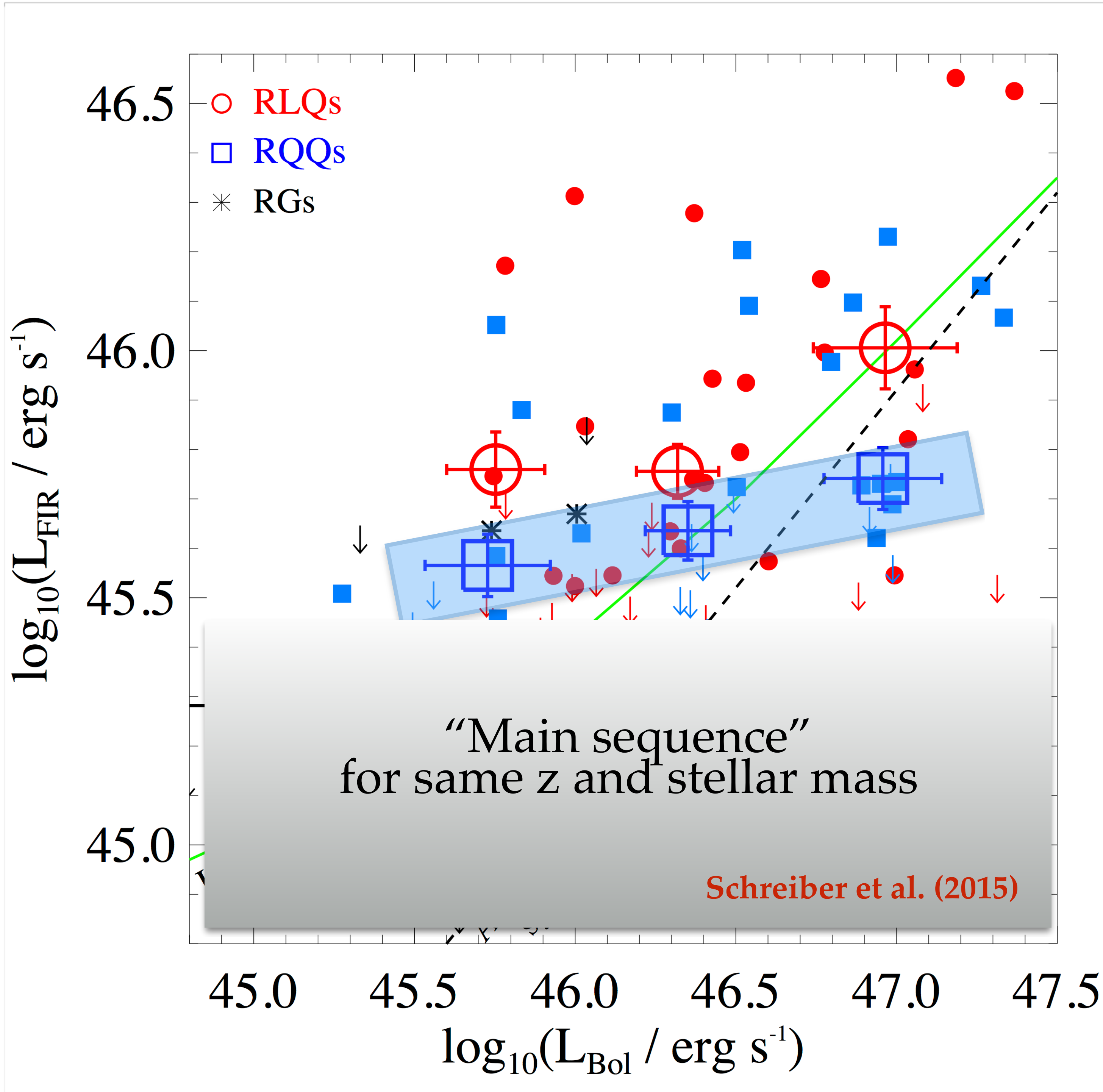
**What about powerful QSOs?**

AGN variability model doesn't describe our observations!

Either alternative models might be required **(e.g. Aird et al. 2013)**

or for these systems the AGN and SF activity are weakly correlated

# QSOs vs. Star-forming Galaxies




**Kalfountzou et al. 2015 submitted**

## What about powerful QSOs?

AGN variability model doesn't describe our observations!

Either alternative models might be required **(e.g. Aird et al. 2013)**

or for these systems the AGN and SF activity are weakly correlated

Although different interpretations are possible, our finding can be explained through periods of enhanced AGN activity and star-forming bursts, possibly through major mergers **(e.g. Elbaz et al. 2011)**

# Summary

- **Powerful QSOs at a single redshift epoch**

  No apparent correlation between BH and galaxy growth

  Evidence for recent merger events

- **Radio-jets are associated with positive feedback**

  But gas richness seems to be a requirement

- **Powerful radio AGN have formed their stars and higher redshifts**

  Possible explanations: association with rich clusters which peak at higher redshifts

- **Compare the results to different evolution epochs**