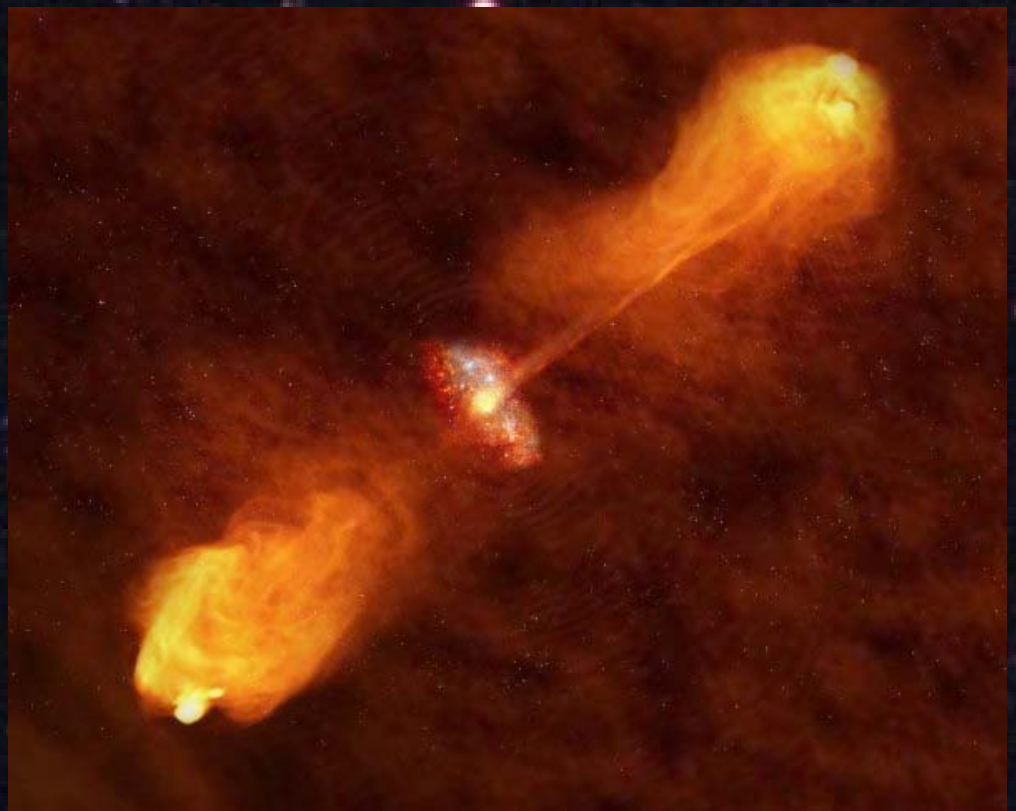
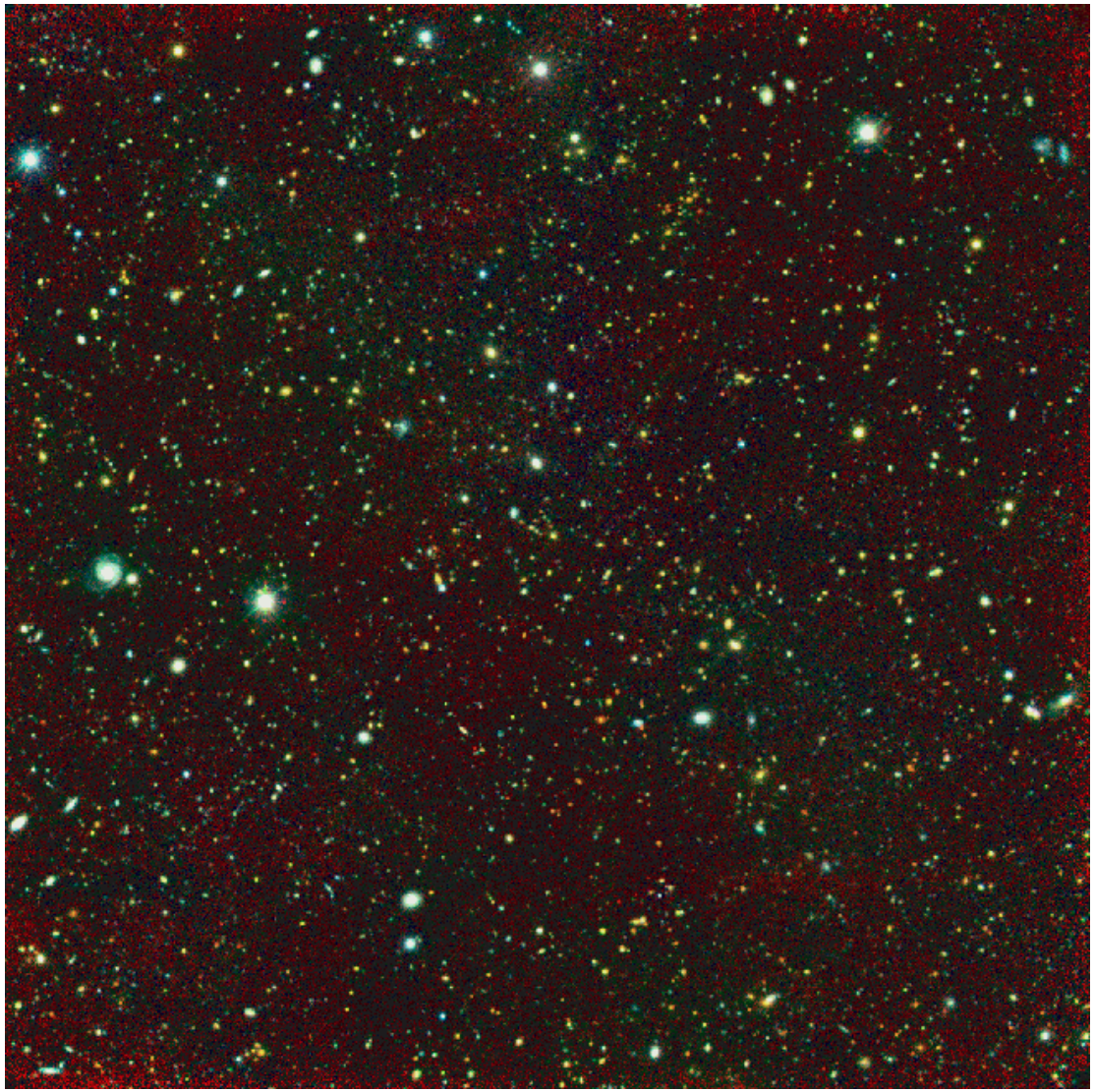
FIREWORKS IN THE EARLY UNIVERSE

Peter Barthel, Kapteyn Institute Groningen,

also on behalf of Pece Podigachoski, Martin Haas, Christian Leipski and Belinda Wilkes

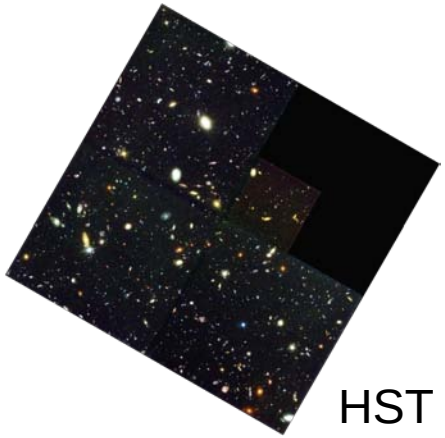


The star-formation history of the universe



HDF-N, V+I+K: Cowie et al.

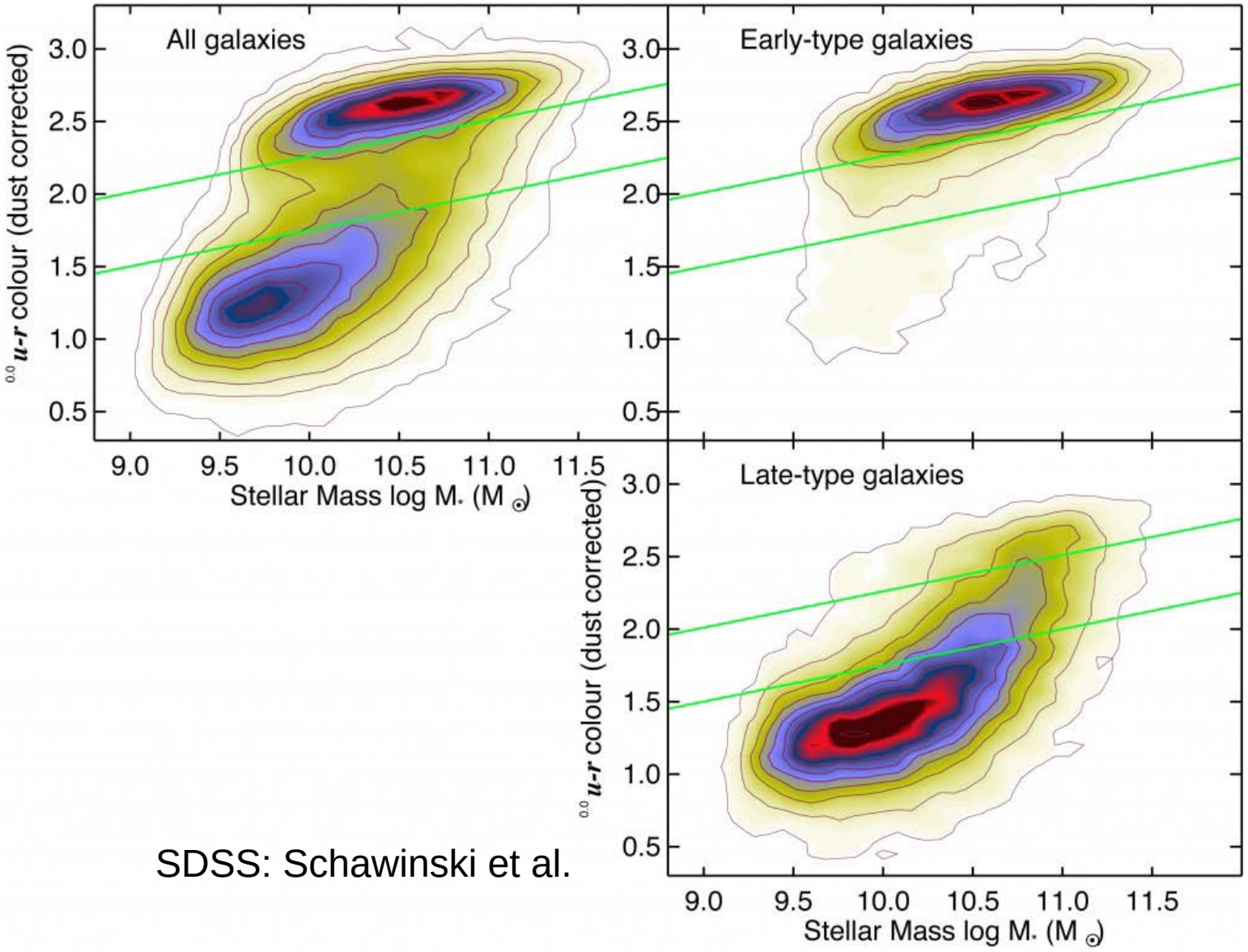
1. Massive galaxies are in place early



HST

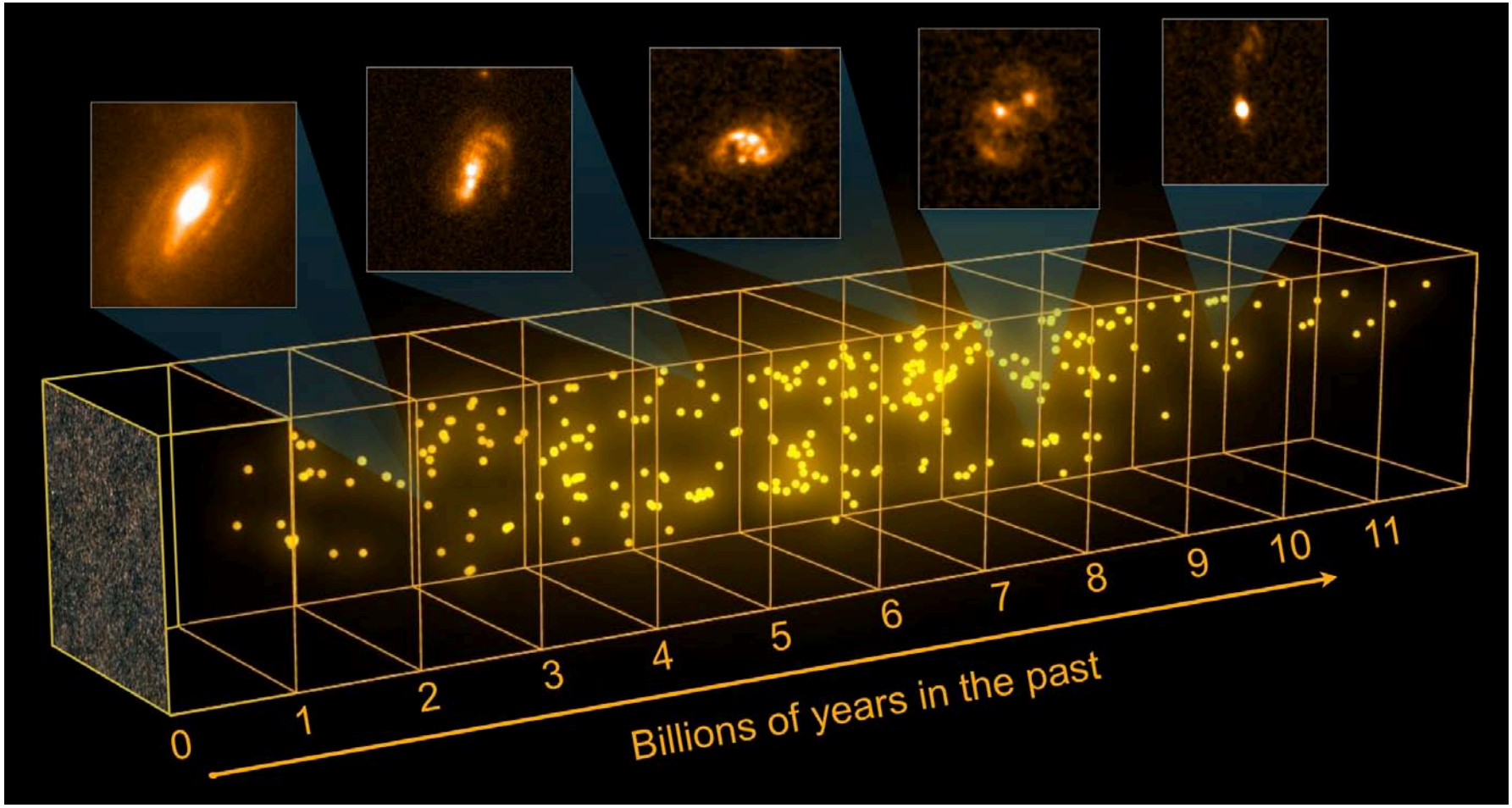
2. SFRD declines rapidly since z ~2

Red sequence, blue cloud and green valley

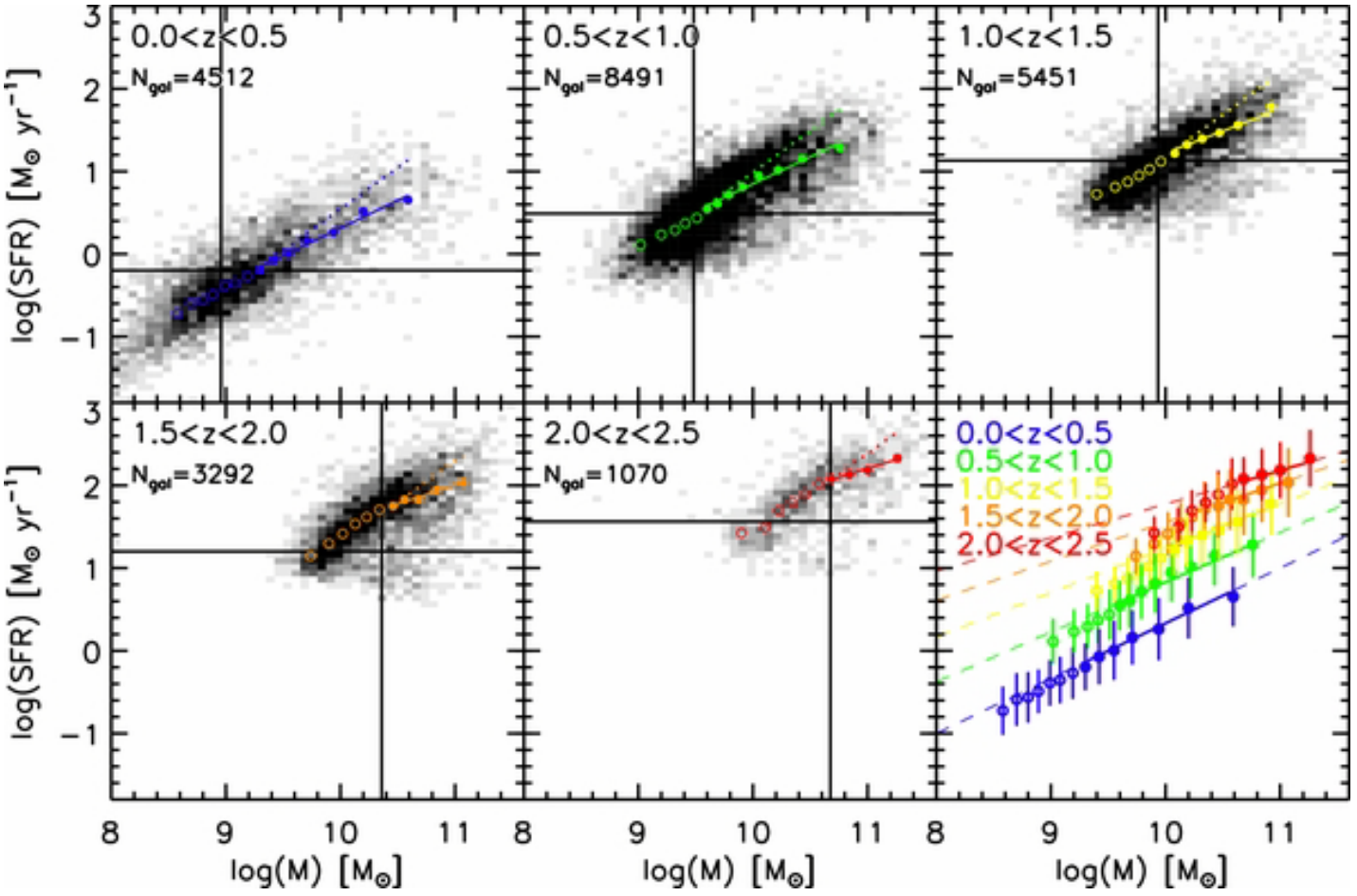


SDSS: Schawinski et al.

SFR(z)

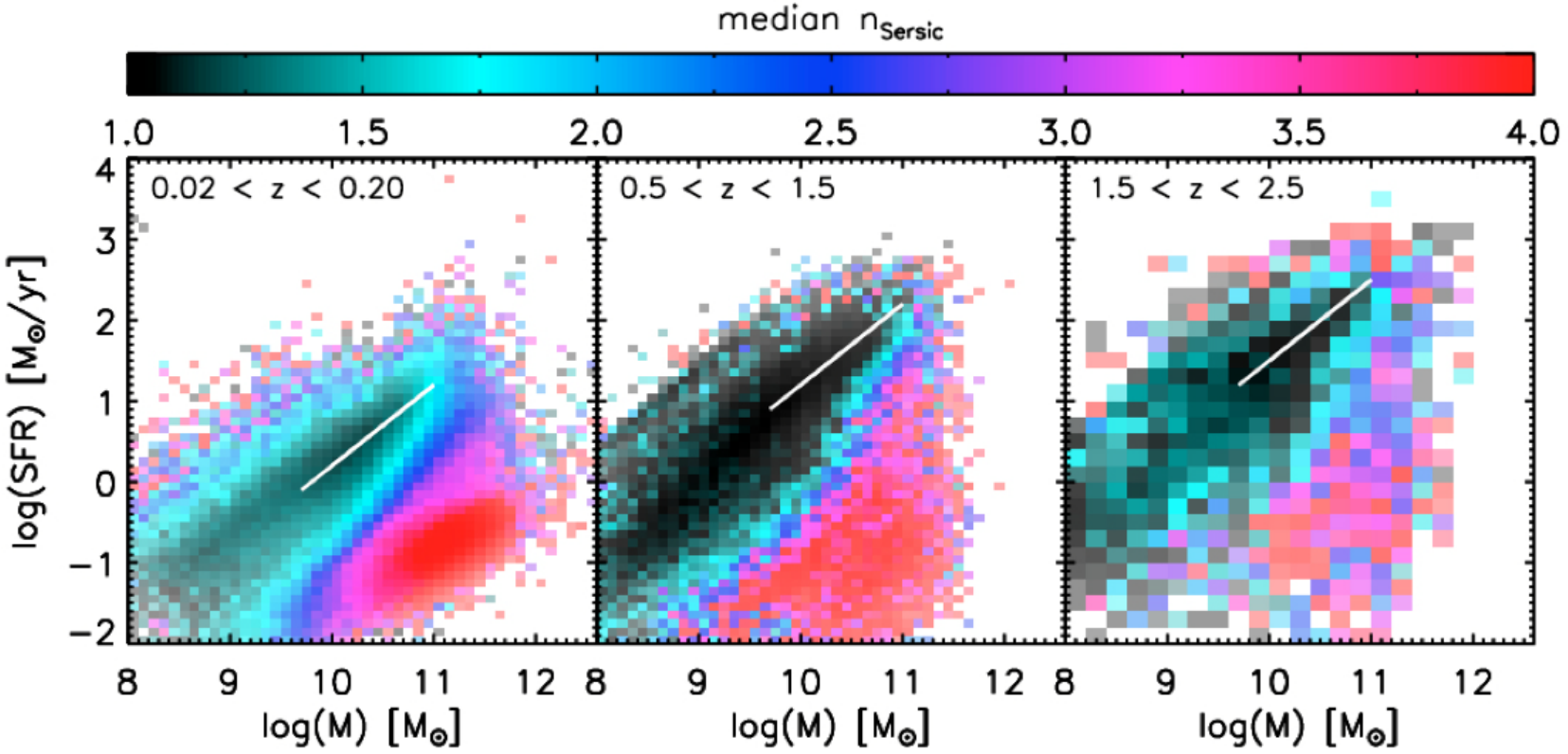


SFR(z) on Main Sequences

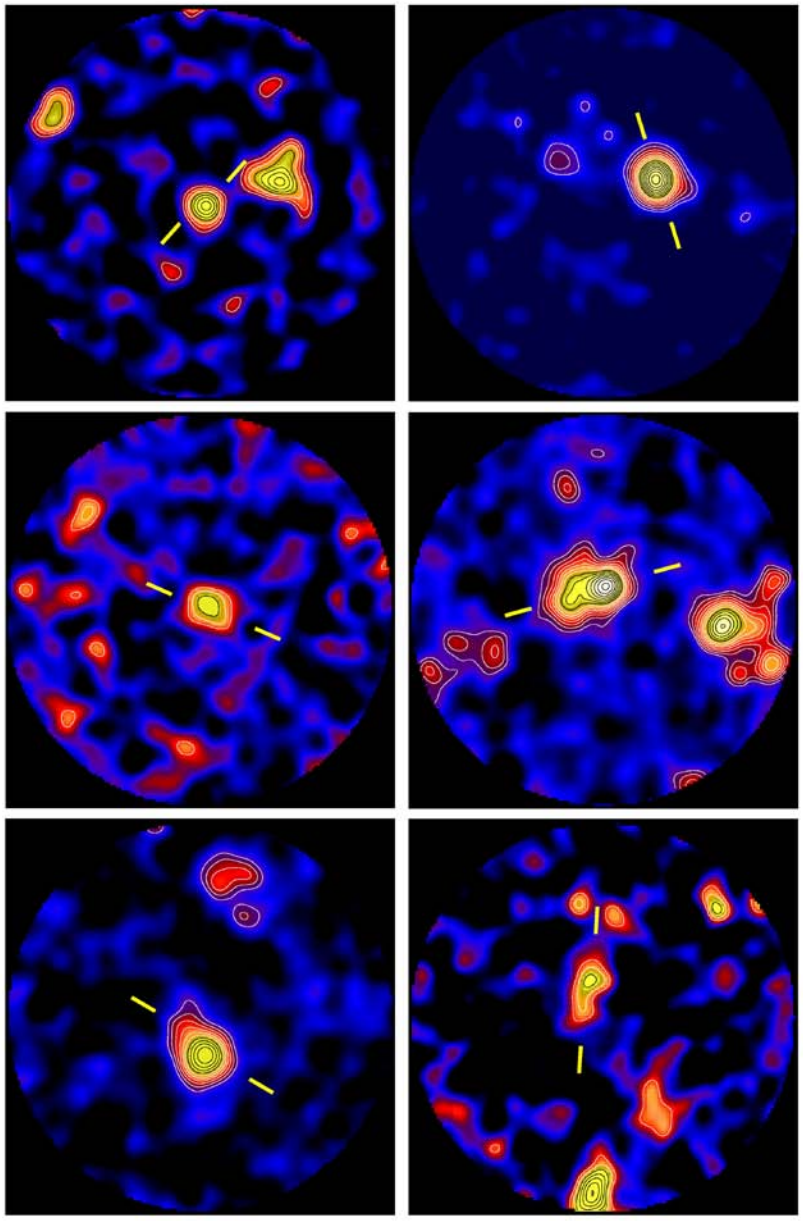


e.g., Noeske+07, Whitaker+12

Morphologies on the MS



Wuyts+

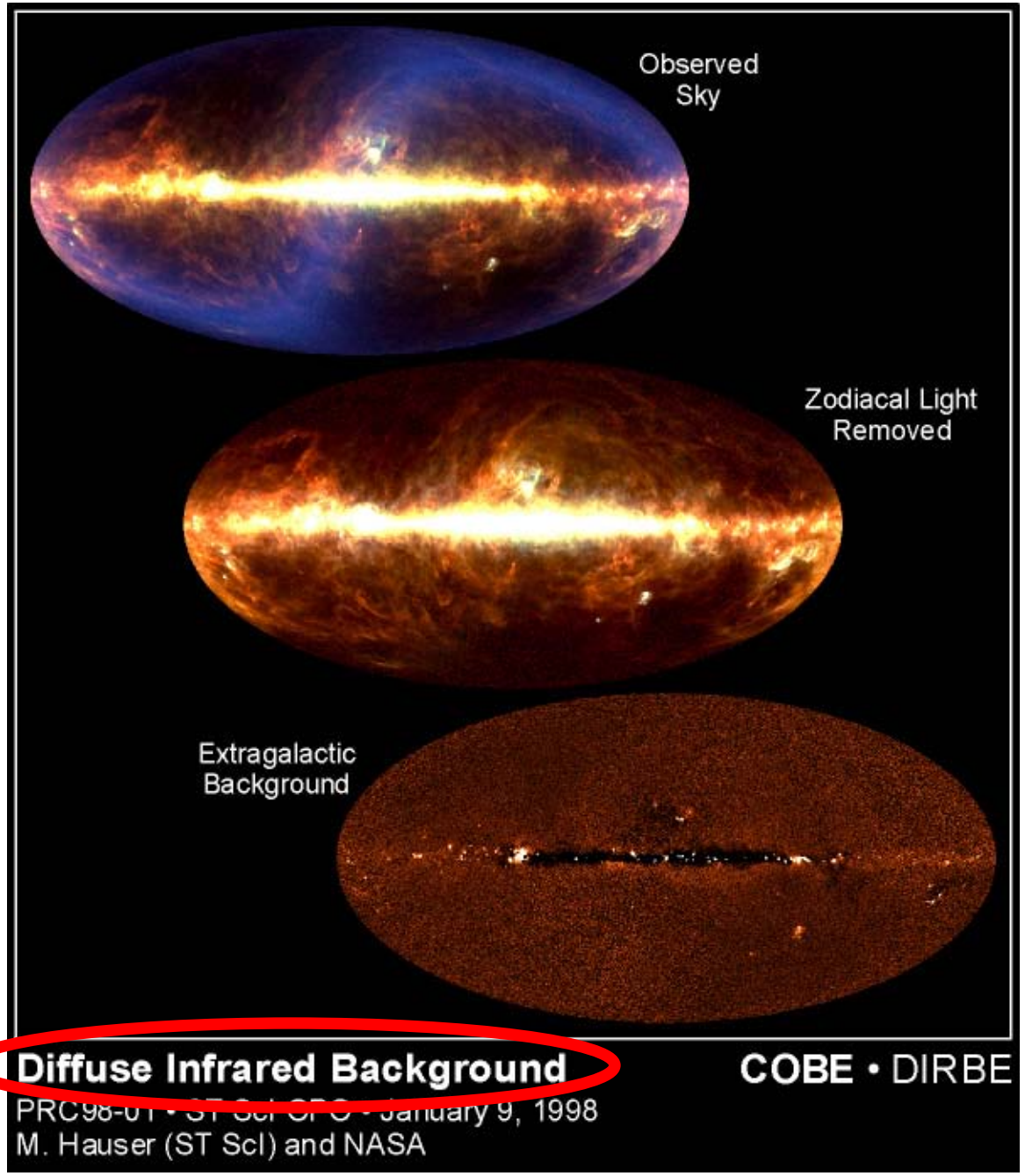


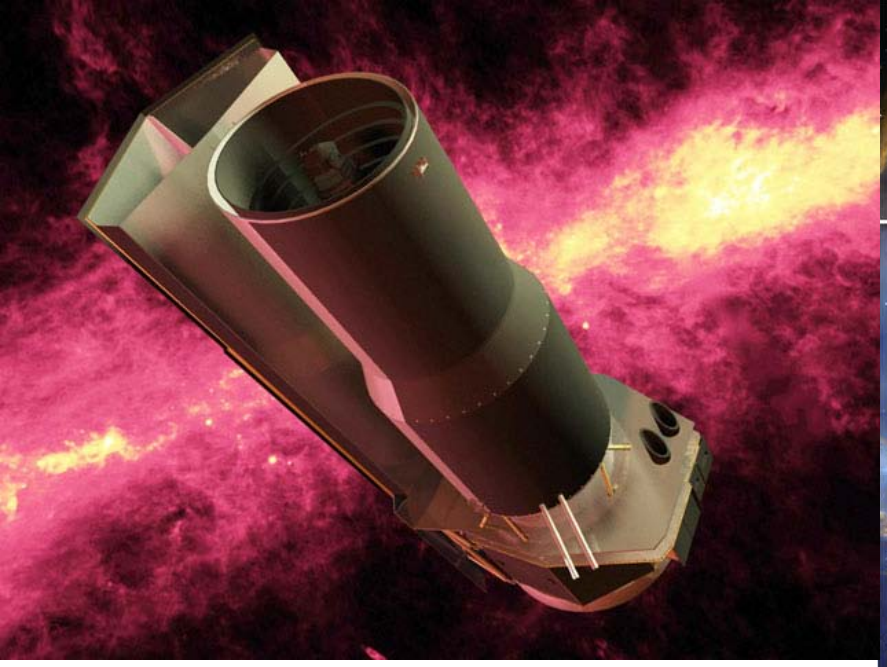
Mid-90s: optically obscured submm galaxies (SMGs): dusty starbursts!

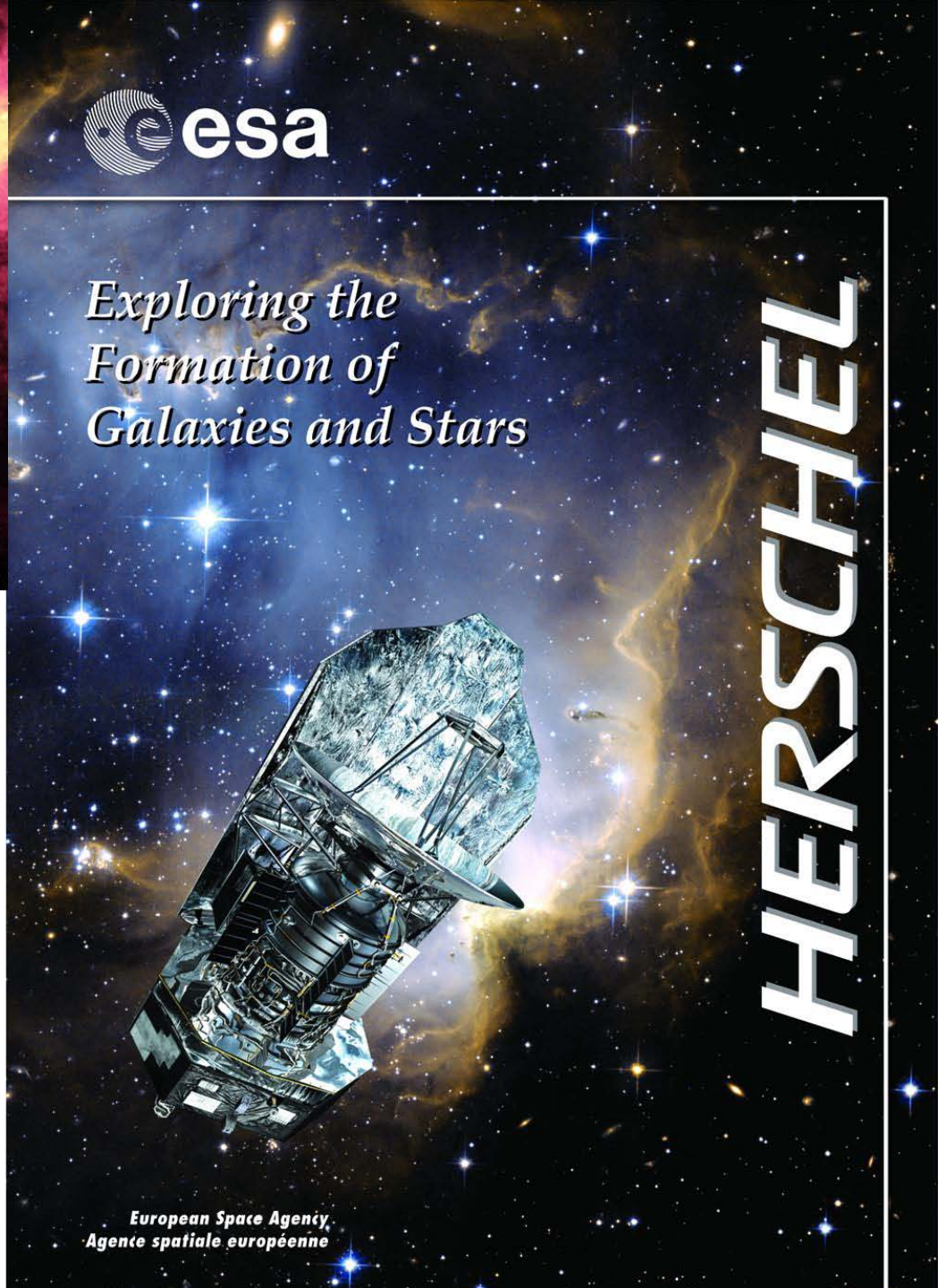
SCUBA also detects certain high z AGN[$] at mm wavelengths: strong star-formers?

[$]radio galaxies and QSOs

Another Universe …







SF(z) is raison d’etre for the Spitzer and Herschel Space Telescopes

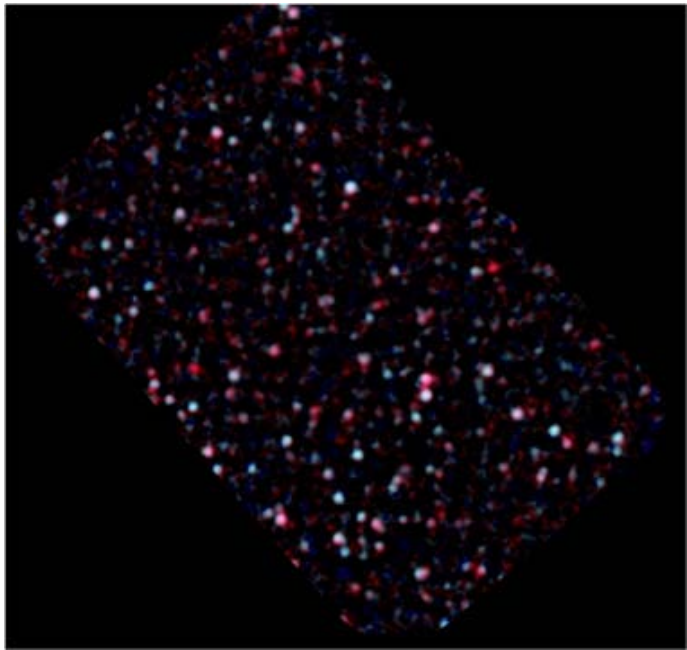
HERSCHEL SCIENCE TEAM (2009, just few months before Herschel launch)

… would you buy a car from these folks … ?

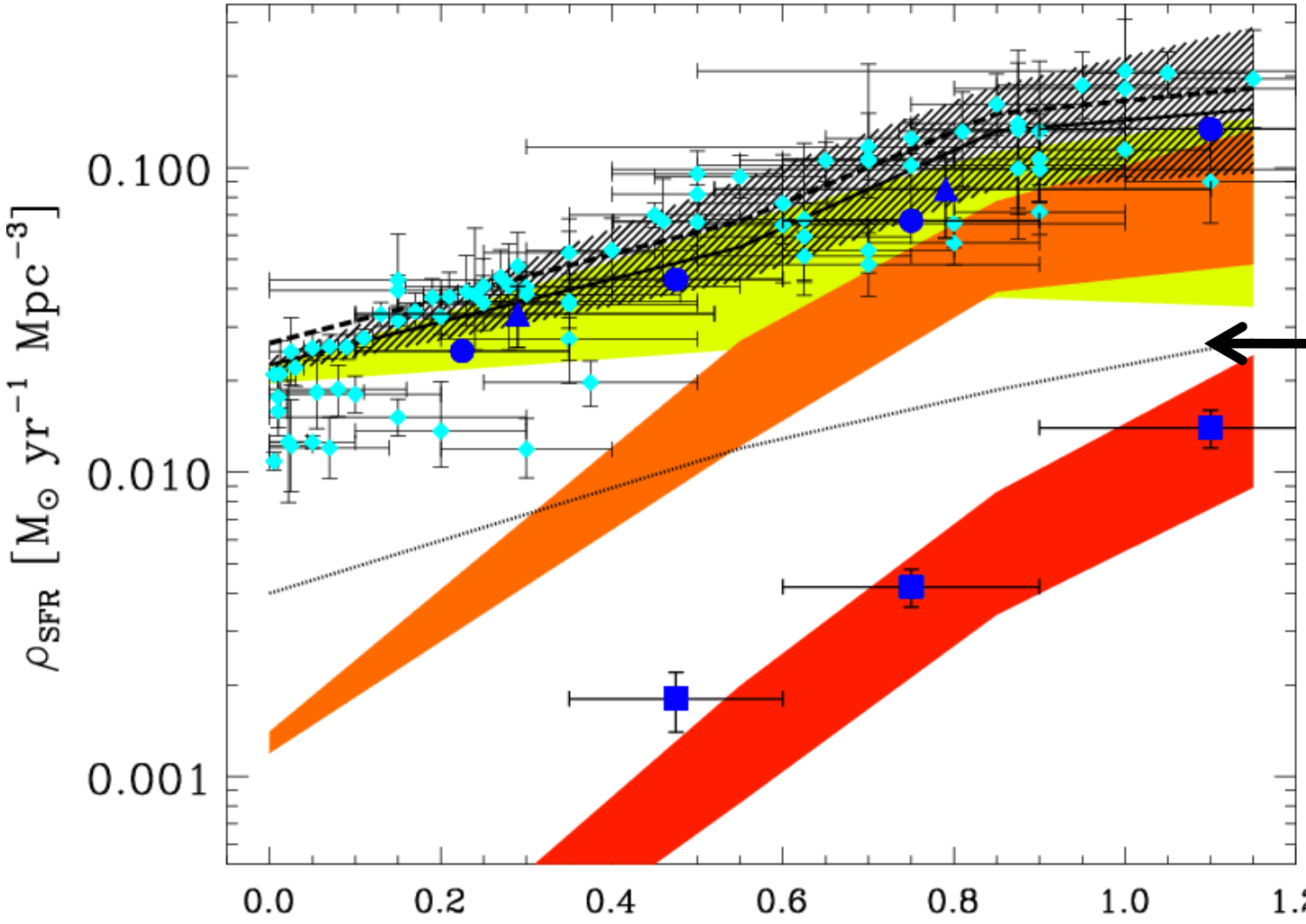

esa
esa
esa

Herschel deep-field studies: 250/350/500μm maps reveal star-forming galaxies over 12 billion years of cosmic time

idem, 100/160μm



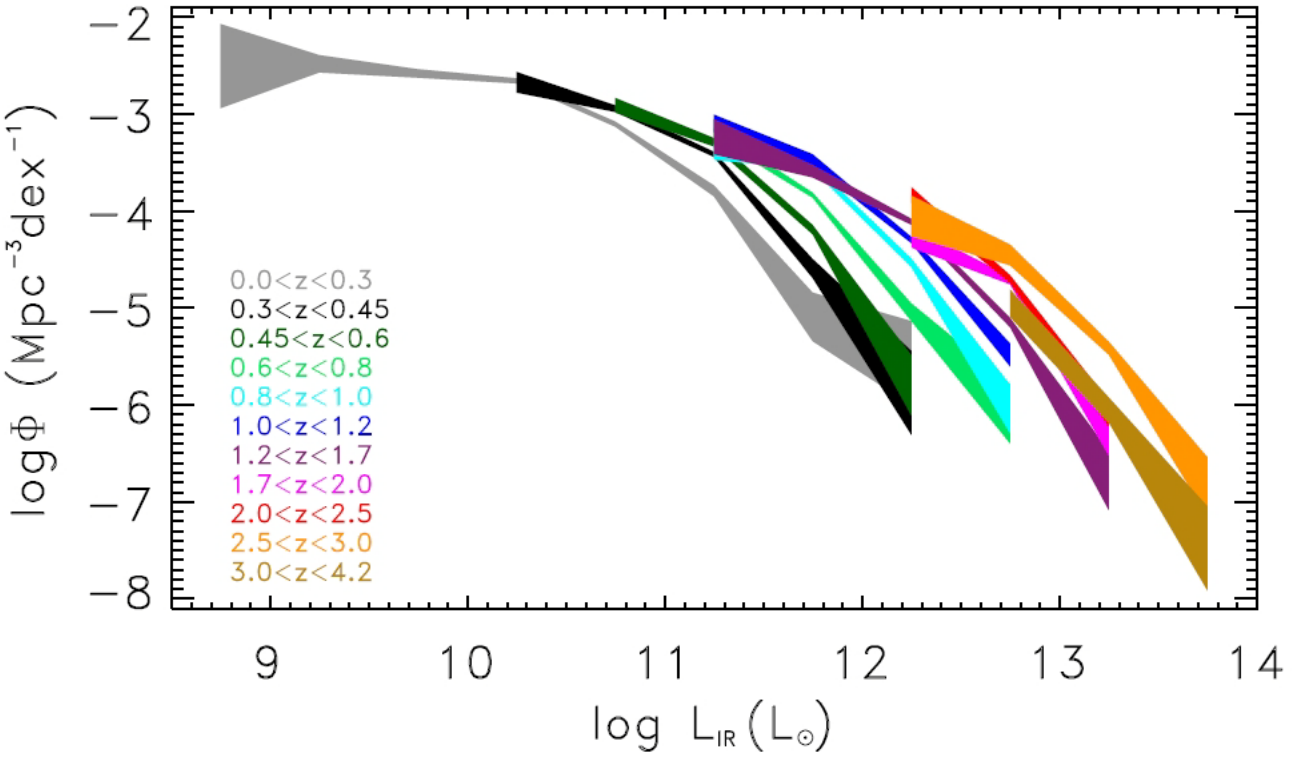
Spitzer revealed the SF(z) populations: normal galaxies, LIRGs and ULIRGs



direct uv !

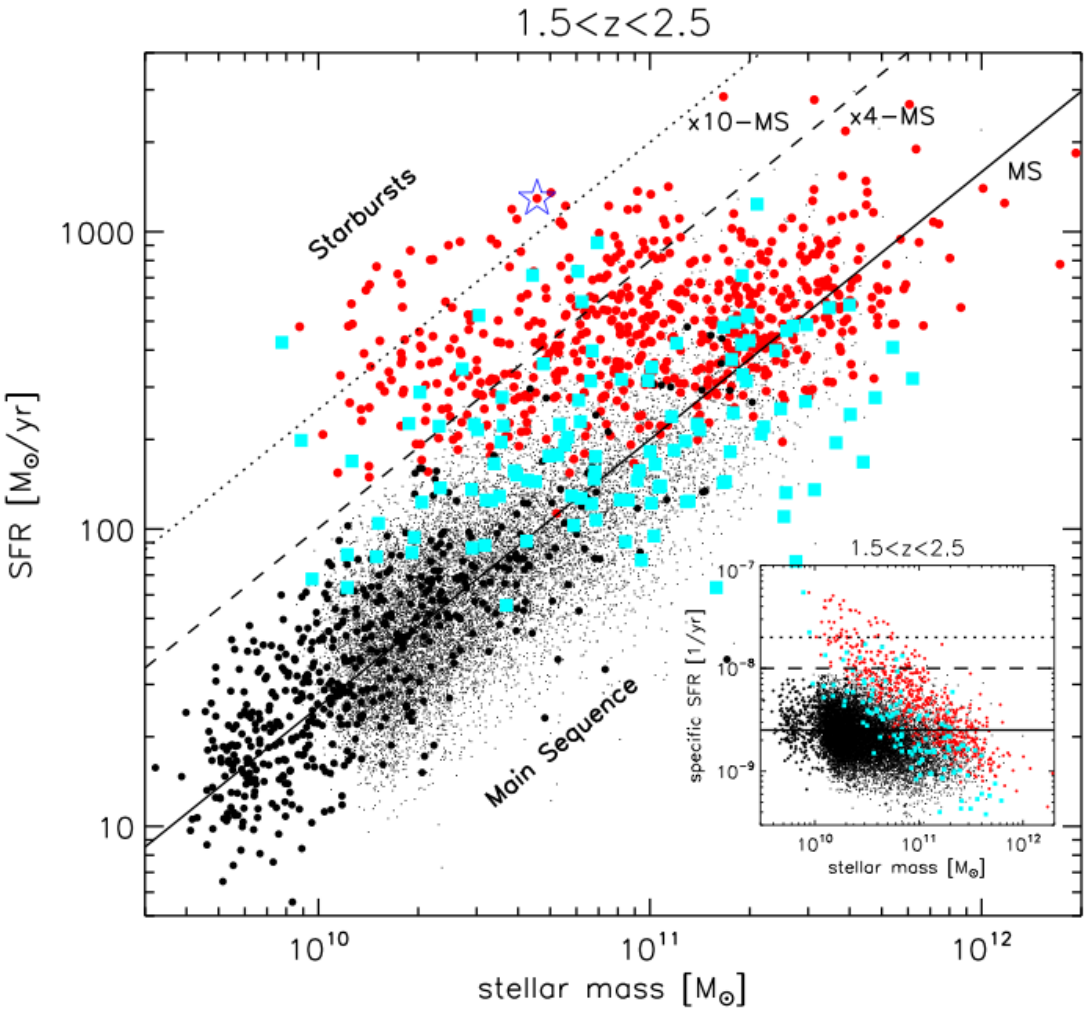
Magnelli+09

Herschel LFs confirm earlier Spitzer work: “ULIRGs are exceptional objects locally, but the norm among massive z~2 star-forming galaxies” (Daddi+)

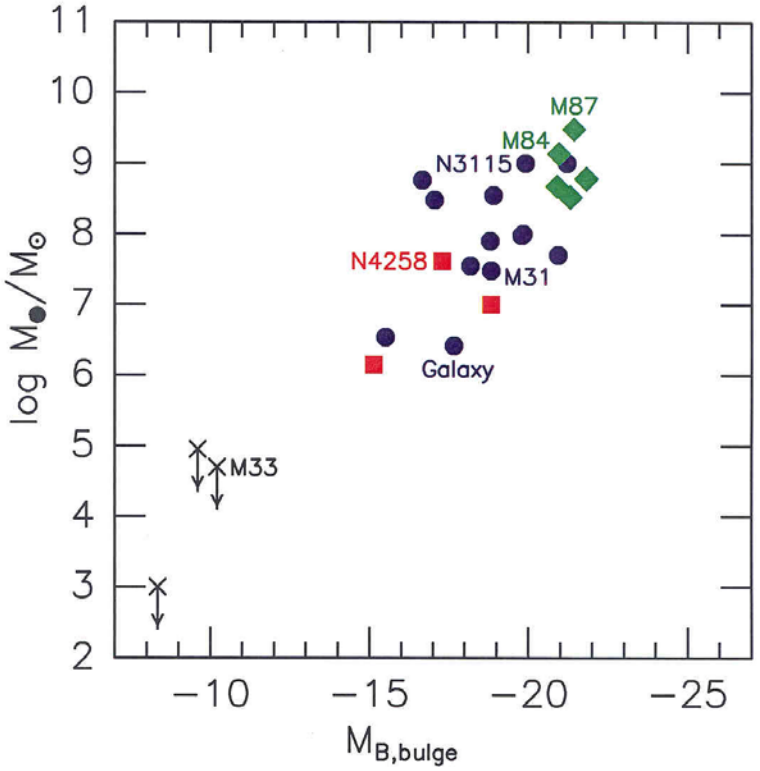


Gruppioni et al.

Herschel has now taken the SFR out to z=2.5: 90% of the star-forming galaxies are on the MS, and “merger-starbursts” represent a small fraction.



Rodighiero+11



Fact of life: the build-up of stellar mass must go in concert with the growth of the central MBH (through AGN activity).

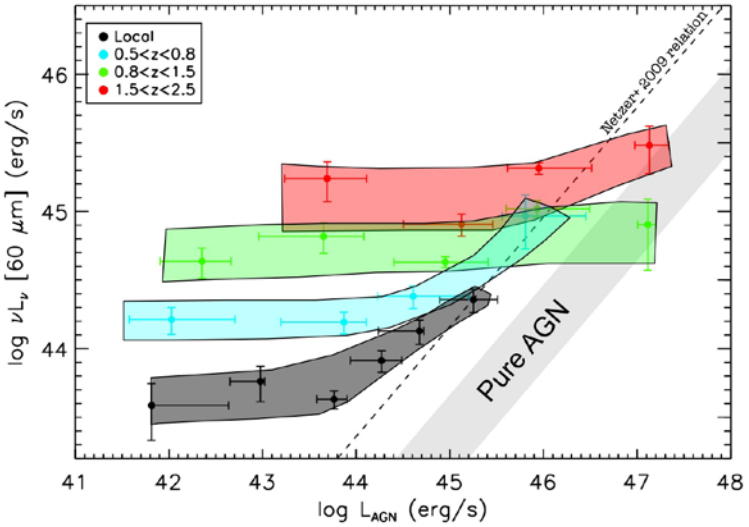
The actual symbiotic occurrence is difficult to observe and/or quantify.

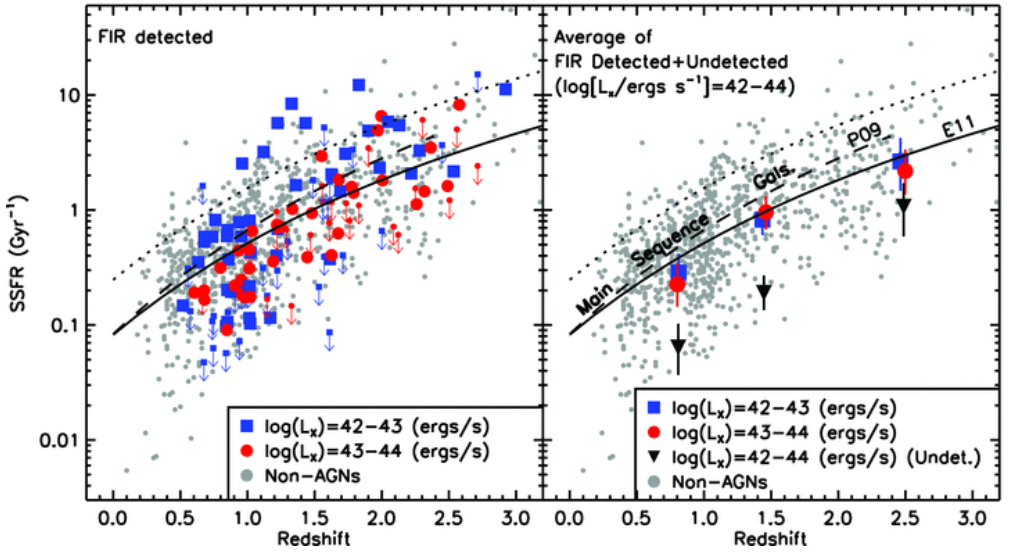
Nevertheless: interplay? coeval? feedback +/- ?

SF-AGN connection, for deep-field X-ray AGN

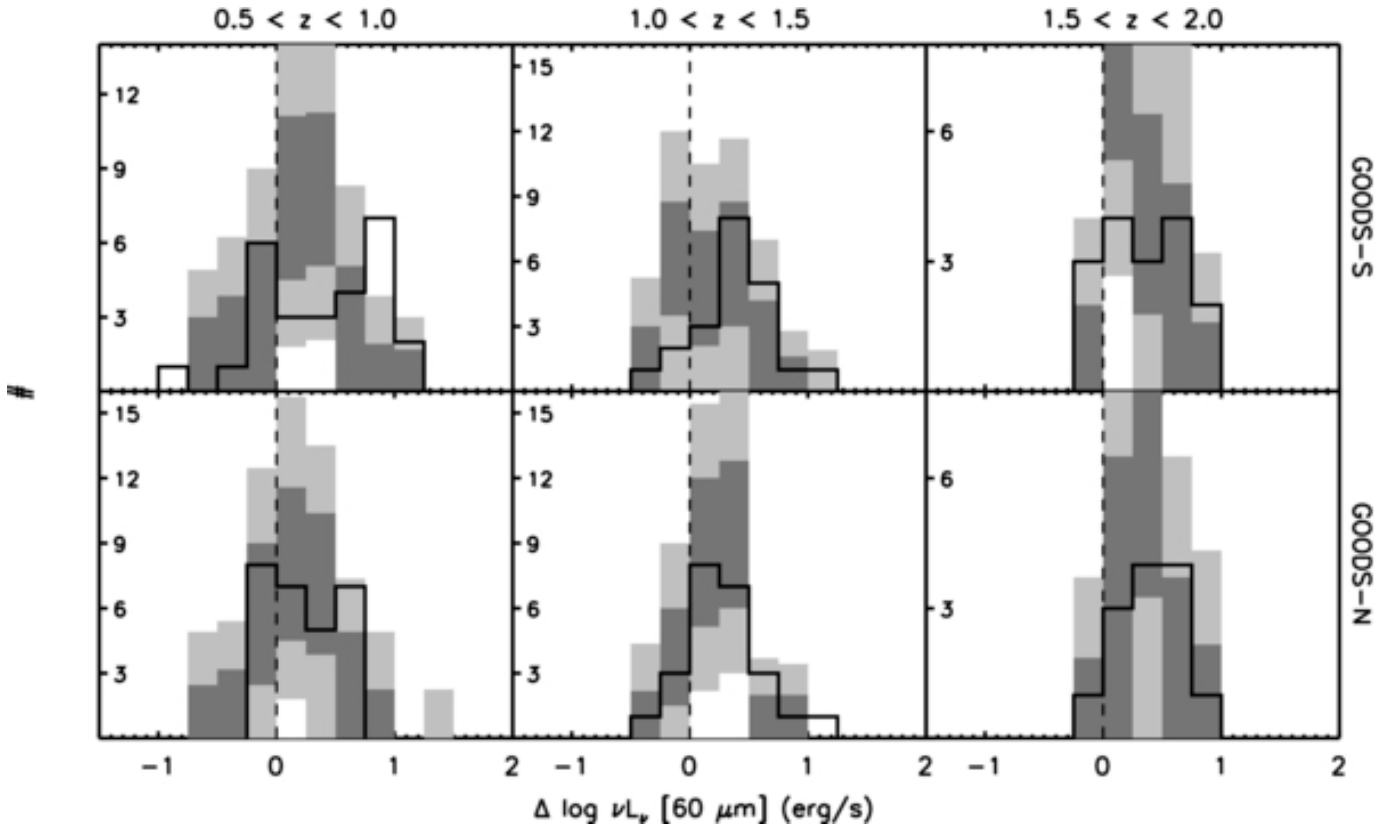
- <SF> higher in AGN hosts as compared to quiescent hosts: ~2 for Seyfert luminosities, ~4 for QSO luminosities (Herschel @ Chandra AGN in deep fields – Rosario+12, Santini+12)

- However, the effects are modest: the global sSFR is observed to rise with a factor 25-50 from z~0.1 to z~2.5, for AGN *and* non-AGN (Mullaney+12)

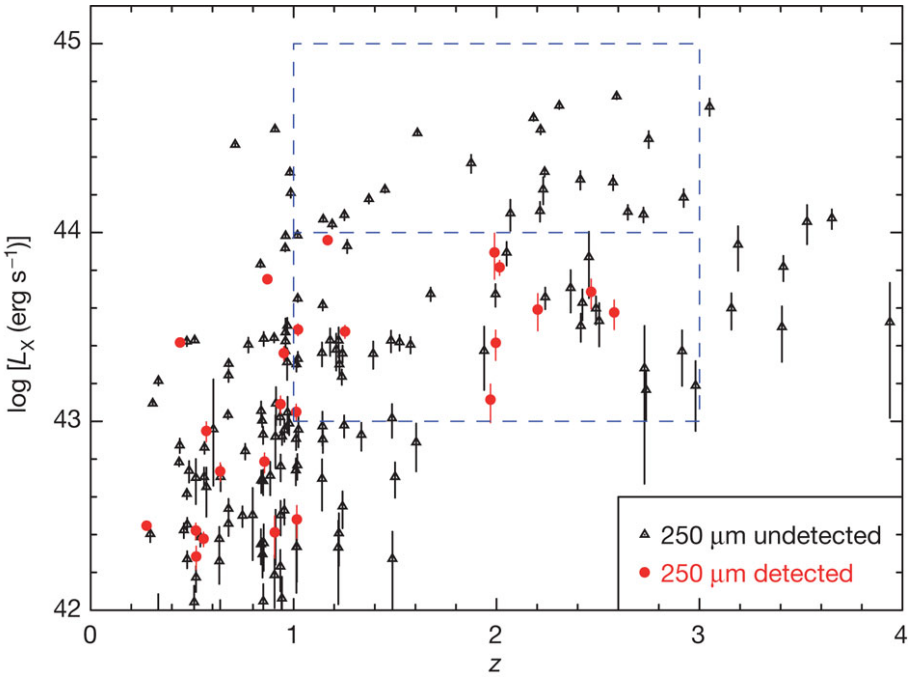




AGN w.r.t. main sequence, in GOODS fields



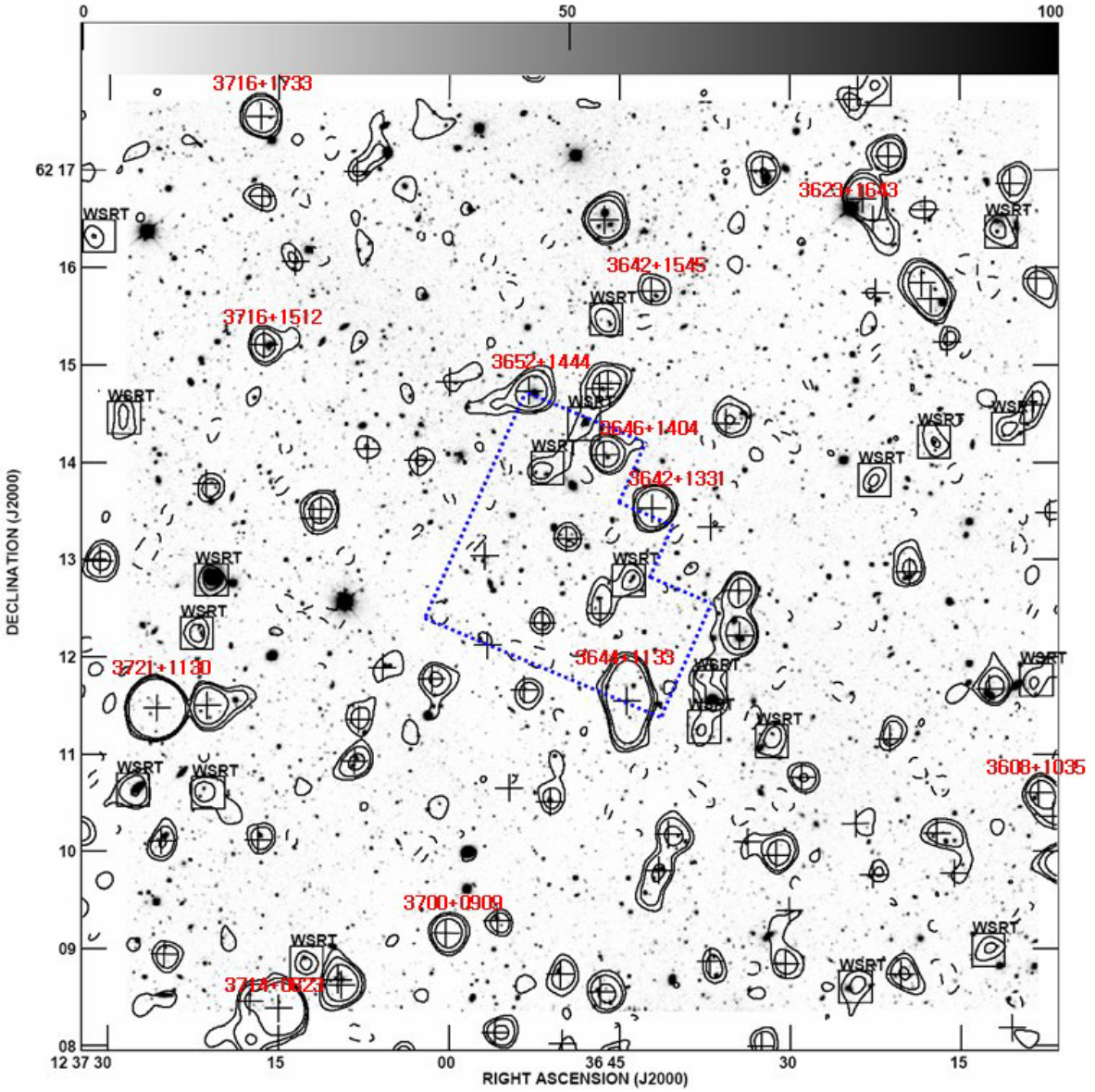
Feedback remains “a vexed question”



The Page+12 (Nature) results - SPIRE detections vs. non-detections in GOODS-N - were not confirmed in larger fields (Harrison+13)

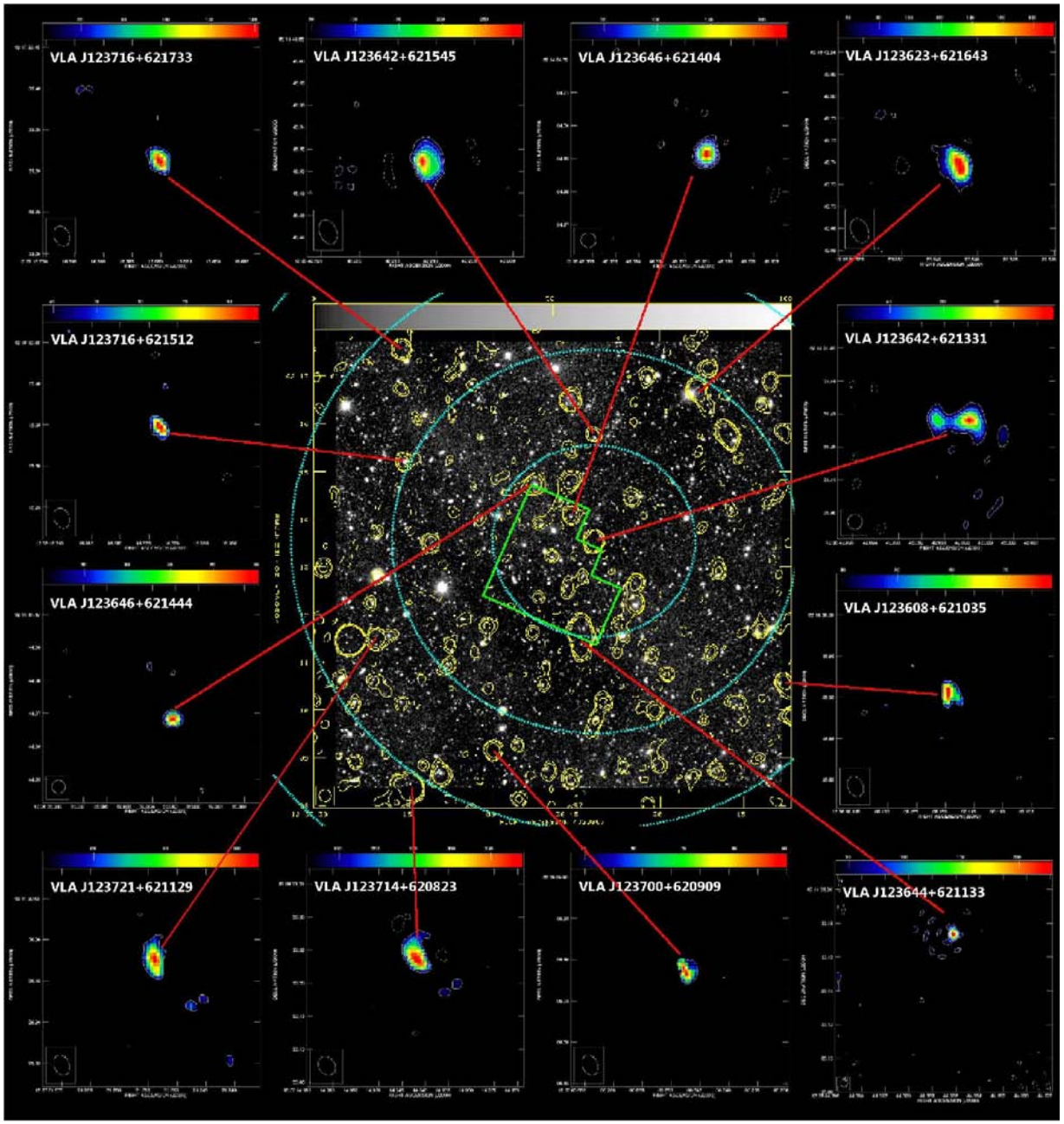

The
radio
night
sky

The faint radio population: starbursts, AGN, or both ?

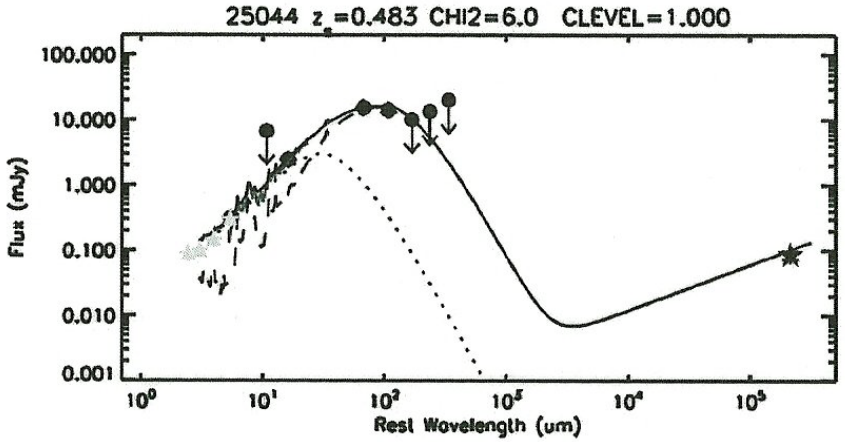


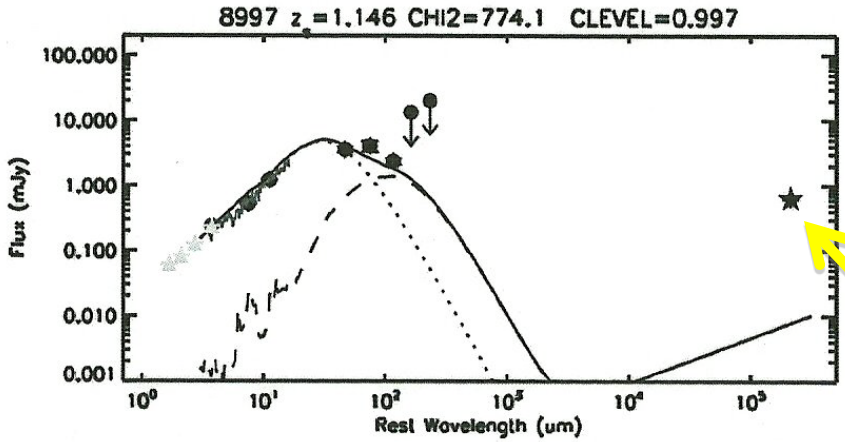
Garrett+08

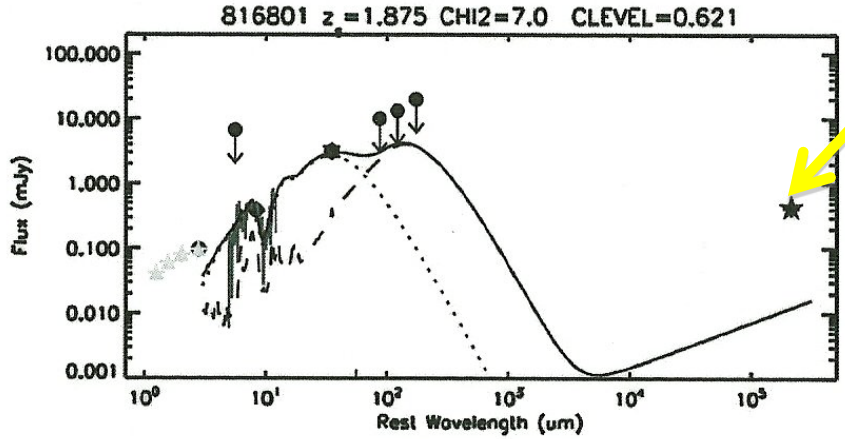
Ultra-deep VLBI of HDF-N, using world array of radio telescopes: ~25% contain weakly accreting AGN (“nowhere to hide..”)



Chi+13







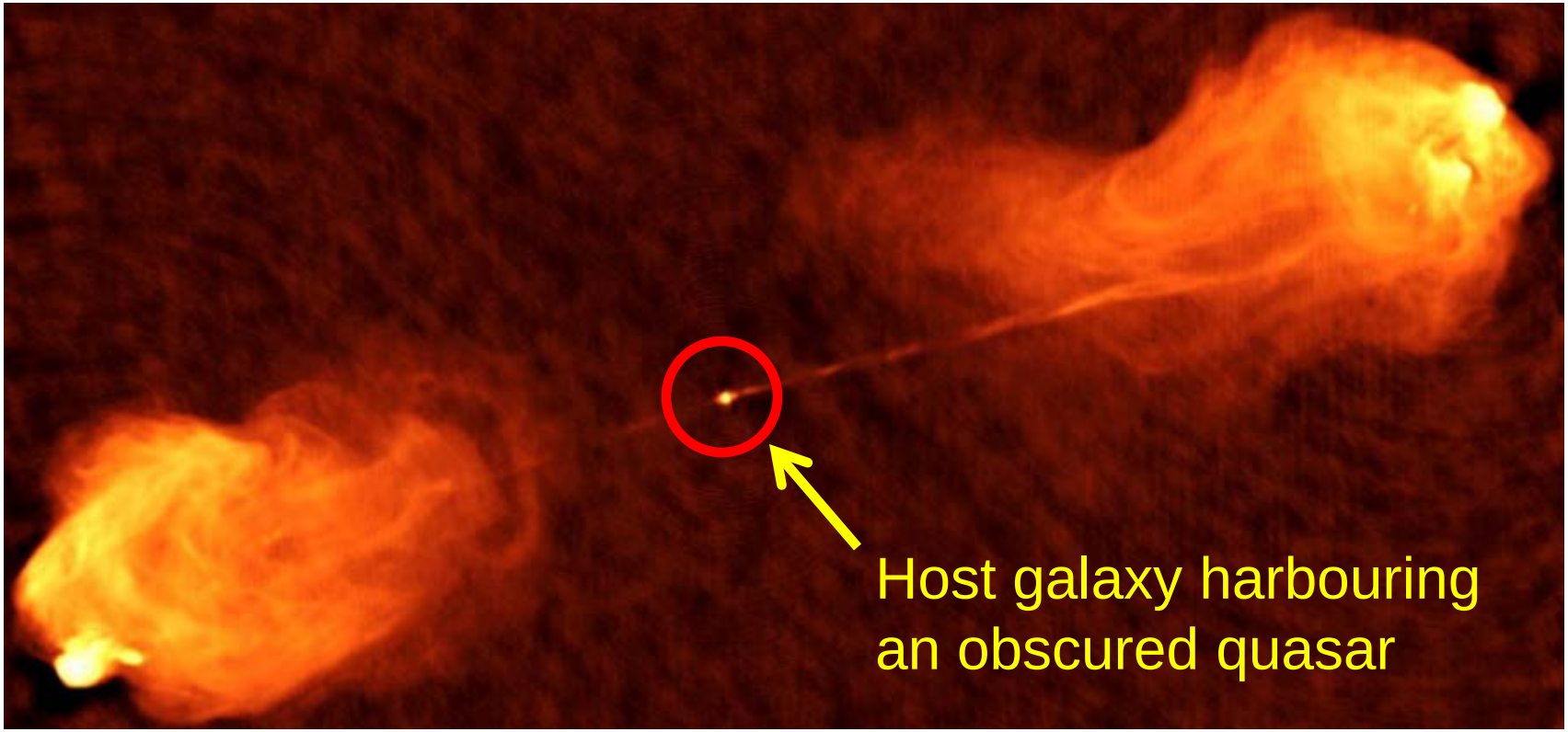
SED fitting incl. Herschel photometry, with techniques developed by Durham colleagues permits independent check of the nature of symbiotic objects

Radio-excess objects, i.e., AGN

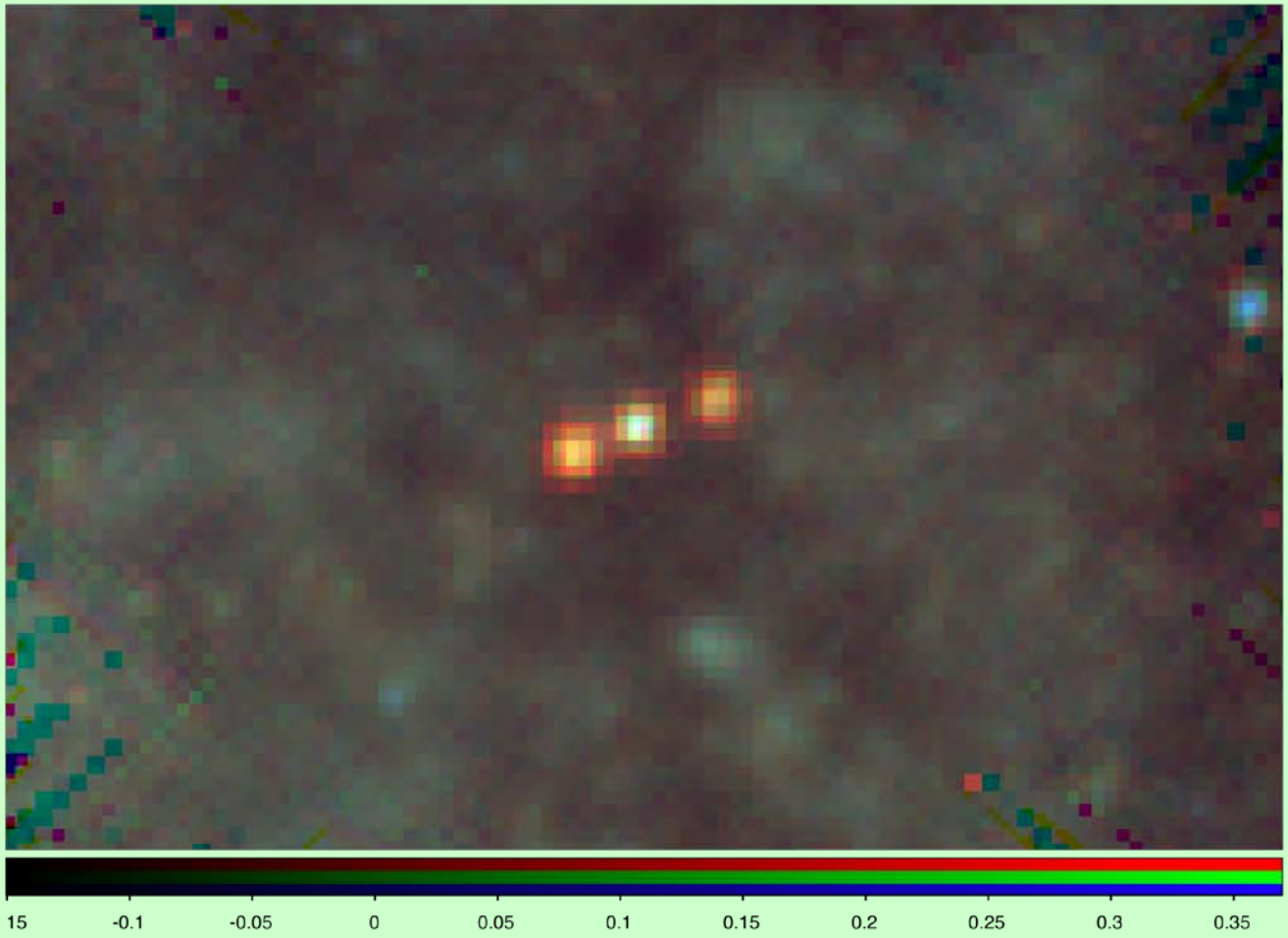
Del Moro+12

Now: the all-sky monsters – powerful FR2 radio sources, a la Cygnus A

Carilli+, VLA



Intermezzo-1 - Herschel/SPIRE image of Cyg A



(Edge/Carilli/Barthel)

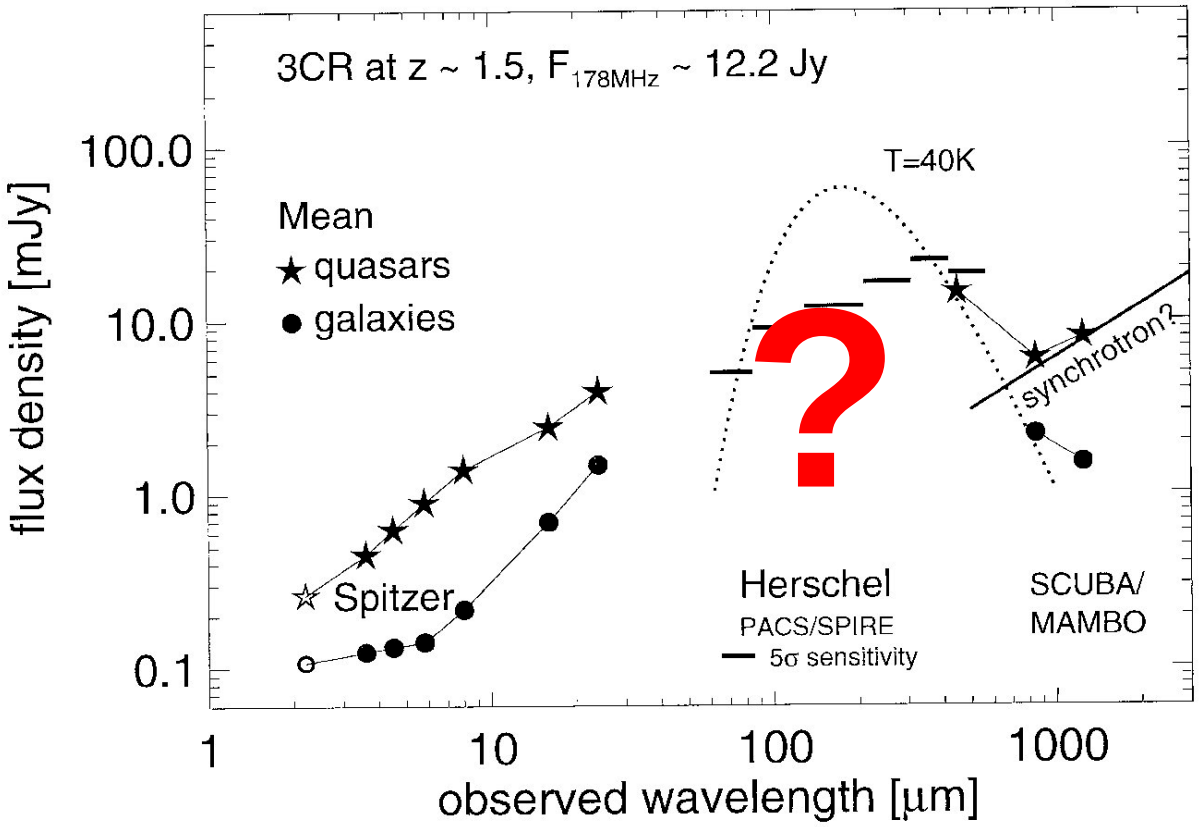
Mechanisms?

Recall: radio AGN is simply (recurrent) $10^{7 \pm 0.5}$ yr episode of MBH accretion in the life of an otherwise normal (star-forming?) galaxy

Age dating of these episodes is possible in radio-loud AGN

Two major Herschel projects are addressing the star-formation activity in the ultra-massive hosts of radio-loud AGN:

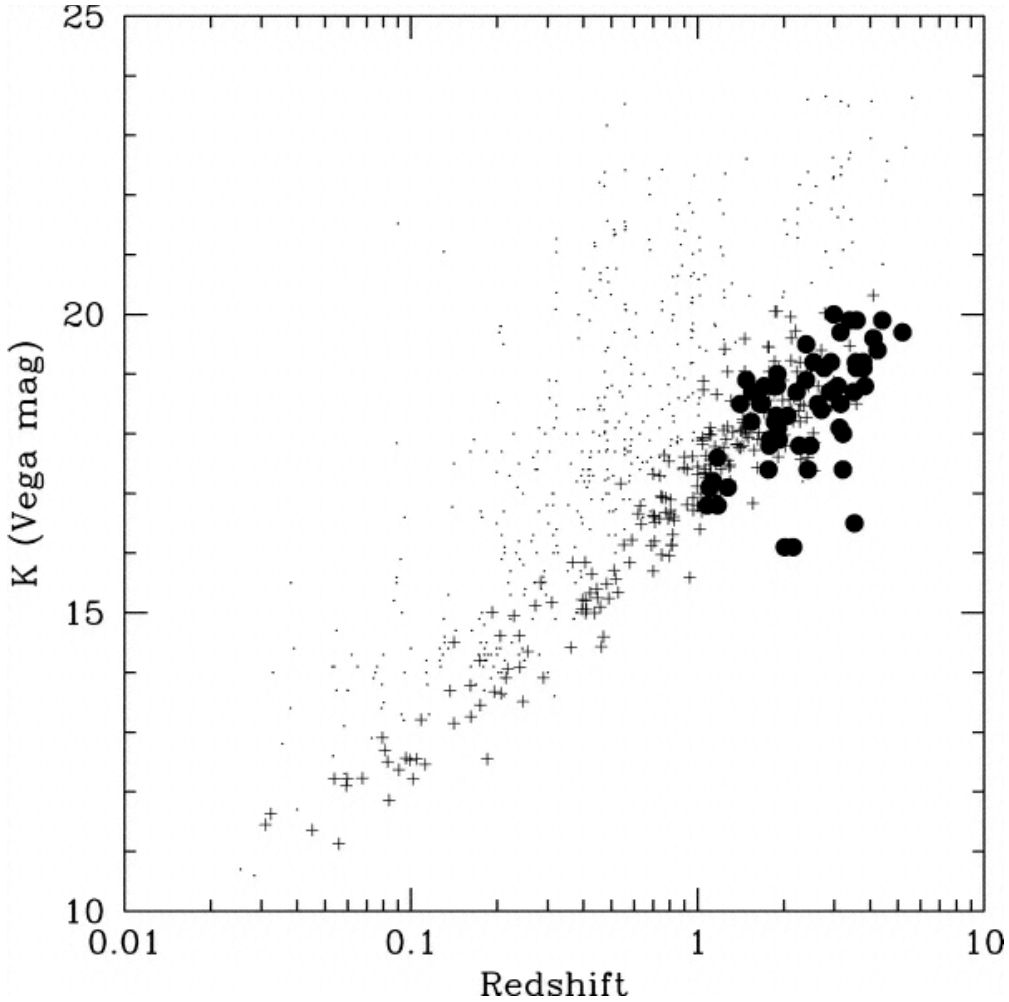
- GT project Barthel+: z>1.5 3C/4C QSRs/RGs
- OT project Seymour+: 1<z<5 RGs



(Spitzer and SCUBA/MAMBO data are in hand)

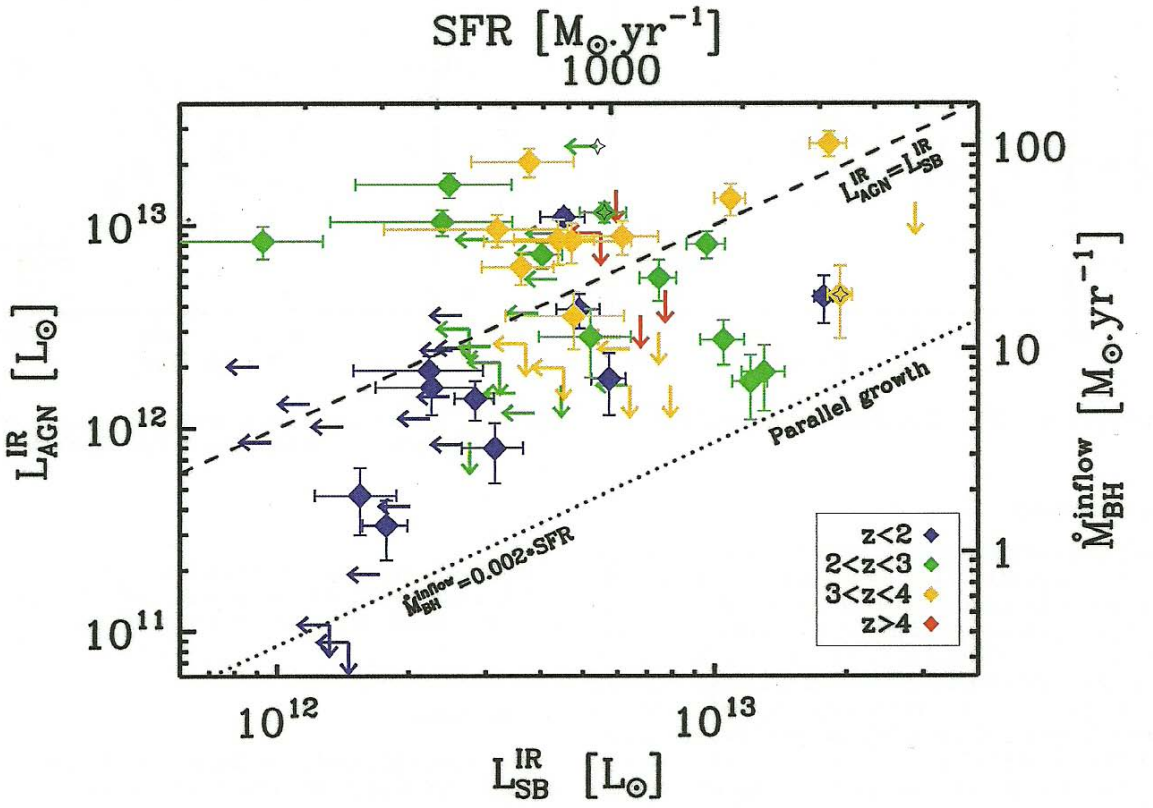
Goal of the 3C/4C program, using the PACS and SPIRE instruments: assess the FIR SED properties of radio-loud high-redshift objects re. the starburst-AGN symbiosis and as unification test

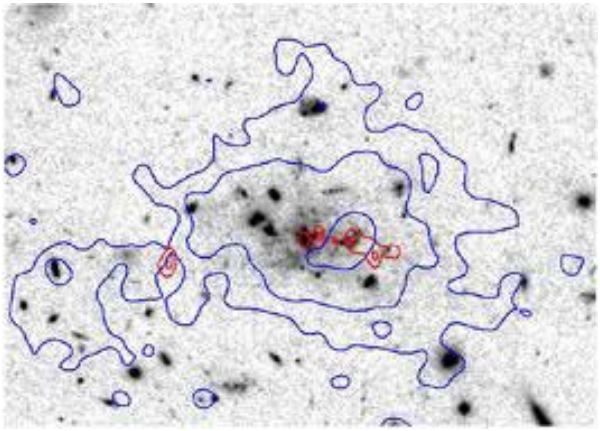
Powerful radio source hosts have ultra-massive host galaxies



K-z diagram, from Seymour+07

Drouart, Seymour et al. (2014, in press) find rapidly growing black holes in star-bursting radio galaxy hosts, such as the Spiderweb galaxy





Intermezzo-2 - HERG vs. LERG

Dichotomy, related to accretion efficiency:

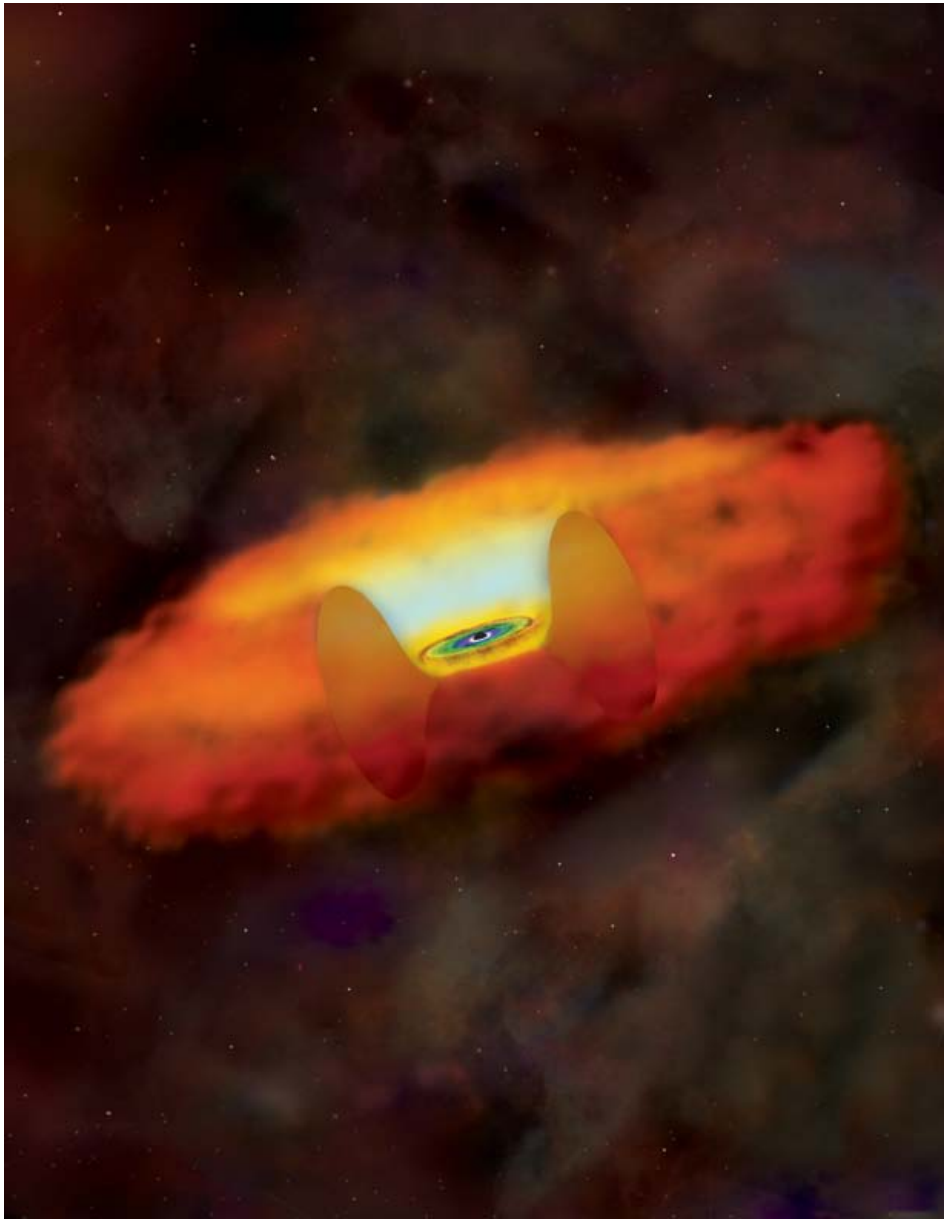
- High-excitation objects accrete at 1-10% of the Eddington rate, presumably cold gas from a minor merger or secular evolution: *quasar mode*
- Low-excitation objects accrete at <1%, presumably cooling hot gas in galaxy/cluster halo: *radio mode* (Best, Heckman & Co.)

! Locally, HERG hosts have bluer colors, lower concentration indices and less pronounced 4000A breaks, due to extended star-formation (and indeed somewhat elevated 250μm emission - Hardcastle+13)

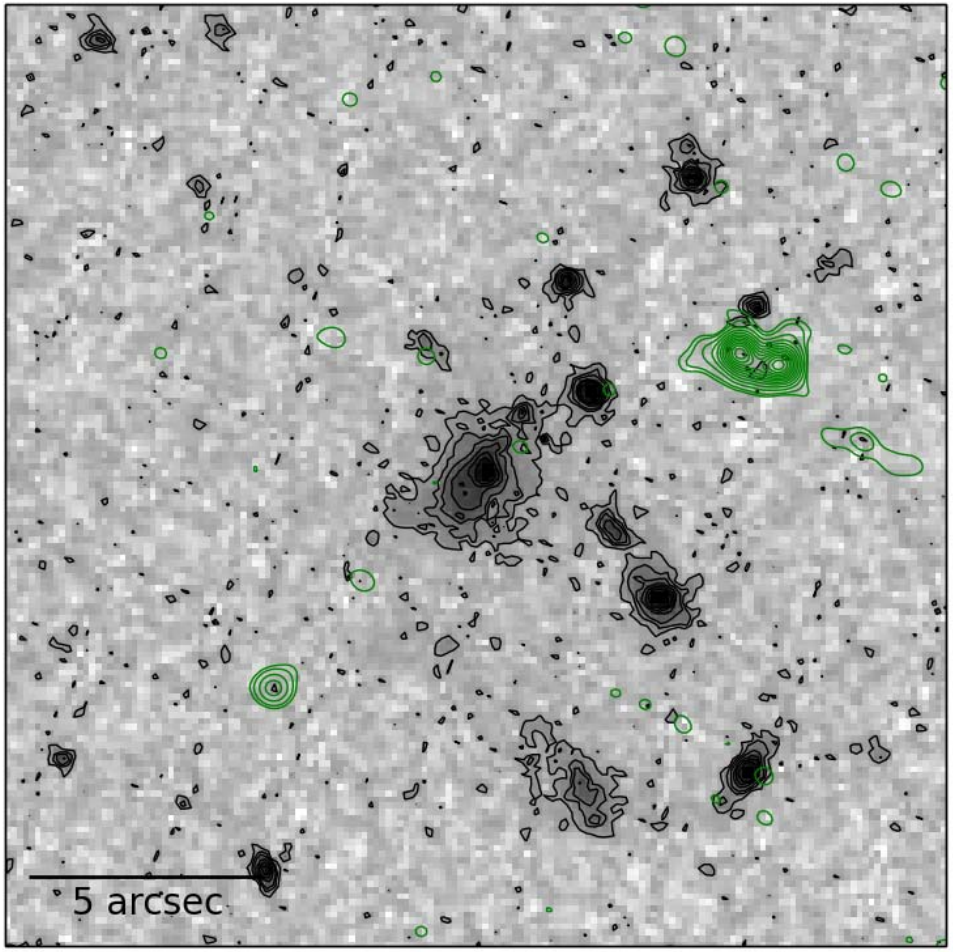
Radio-loud AGN are believed to have circumnuclear dust tori, partly covering their accreting black holes

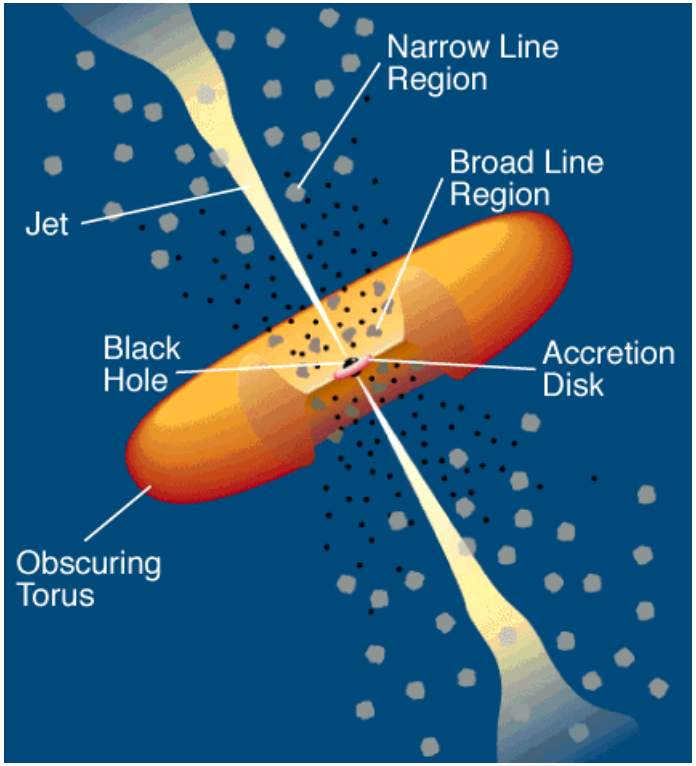
⇒

1) must take orientation into account;
2) radio-lobe selected objects such as 3C represent an orientation-unbiased sample !

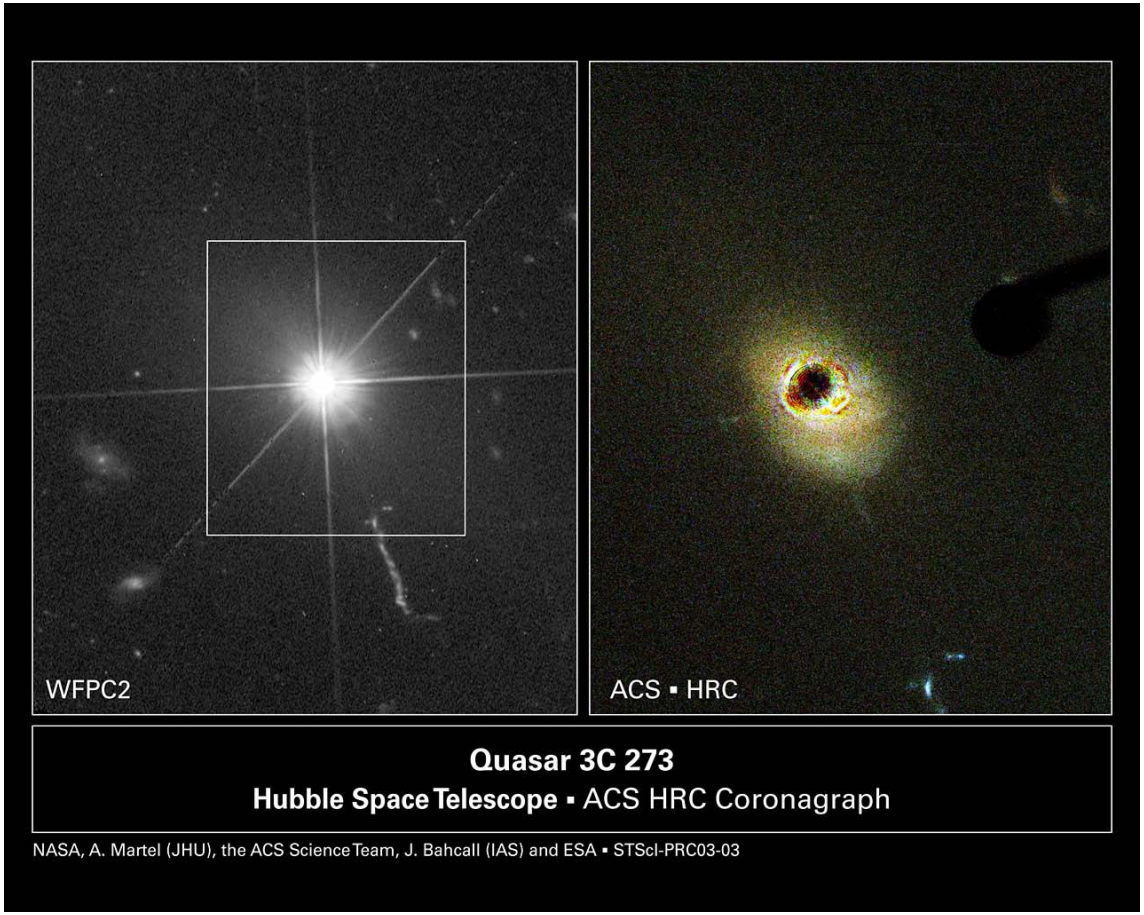


Hence, 3C radio galaxies such as 3C257 (z=2.5) harbour obscured QSOs, …..

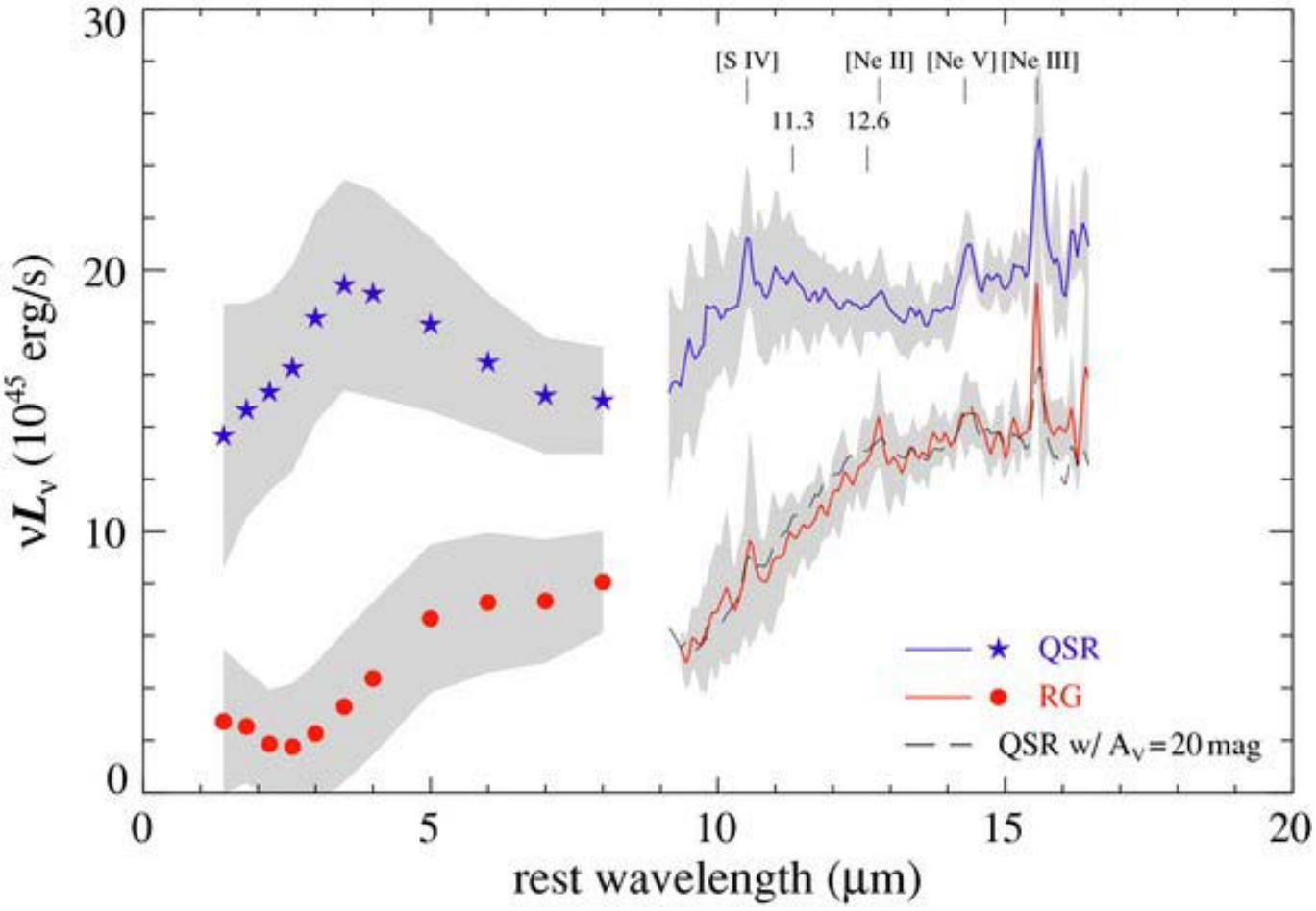




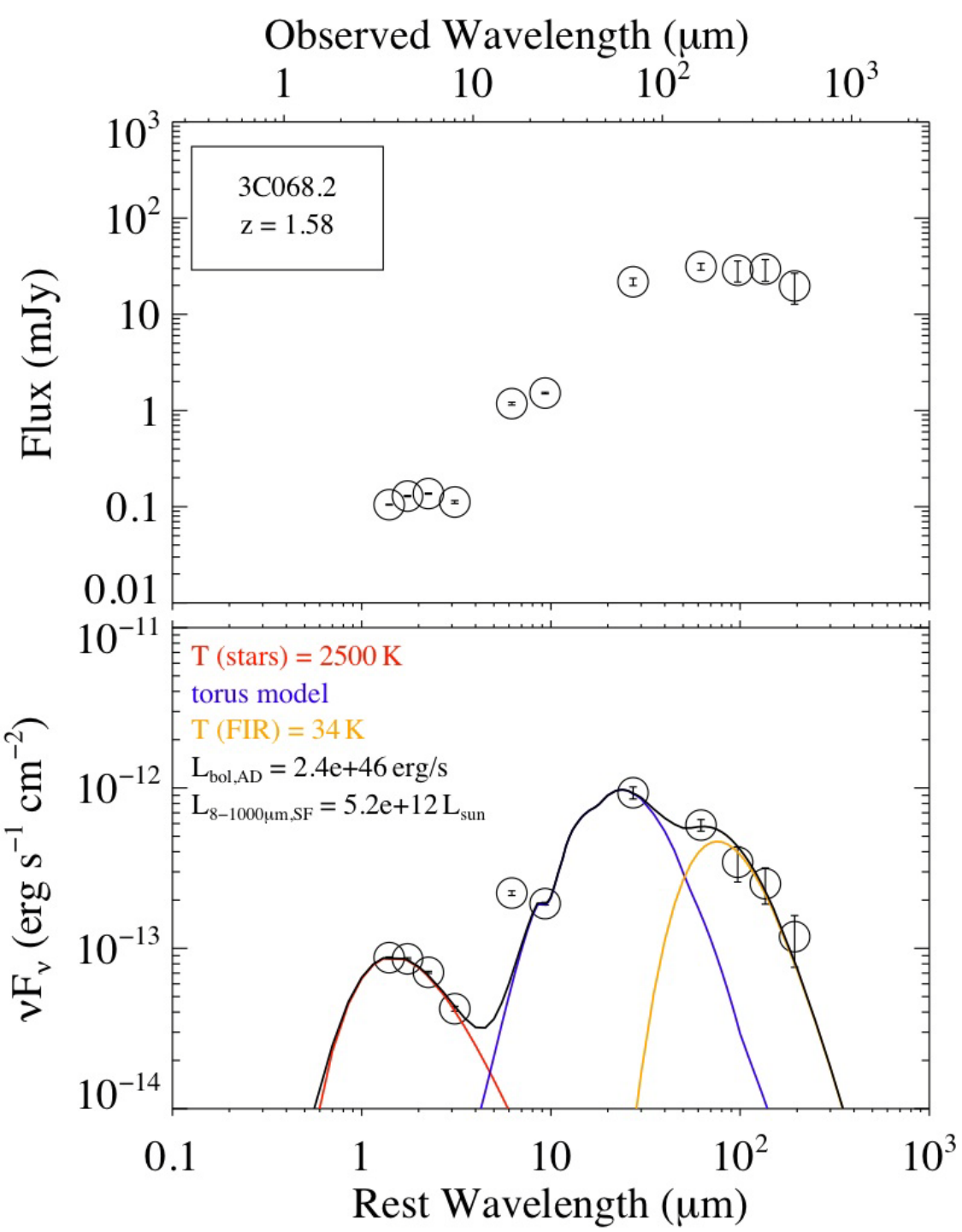
.. and QSRs such as 3C273 would appear as radio galaxies when observed with their radio source axis at large inclination



Spitzer IRS confirms:



Leipski+10

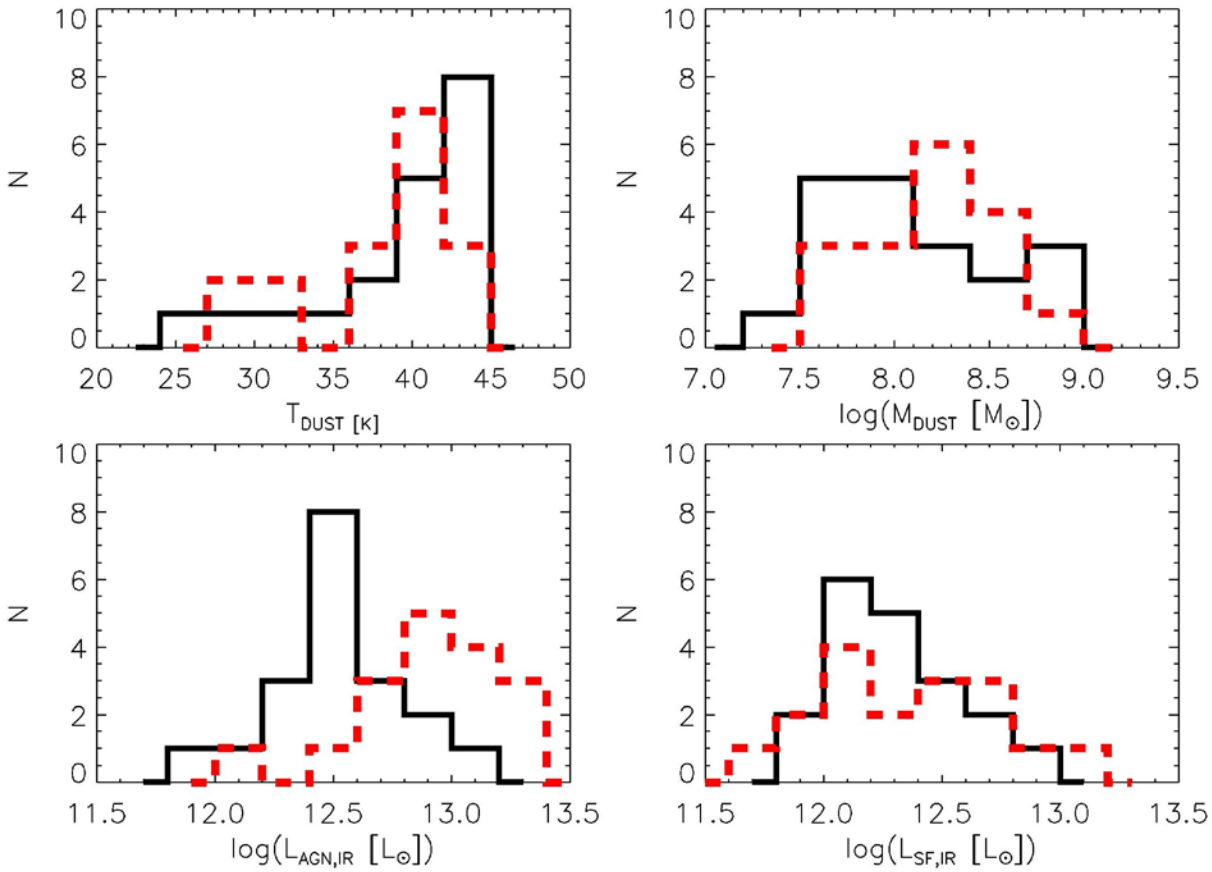


First result of 3C/4C: prodigious star-formation in several high z radio galaxies (Barthel+12).

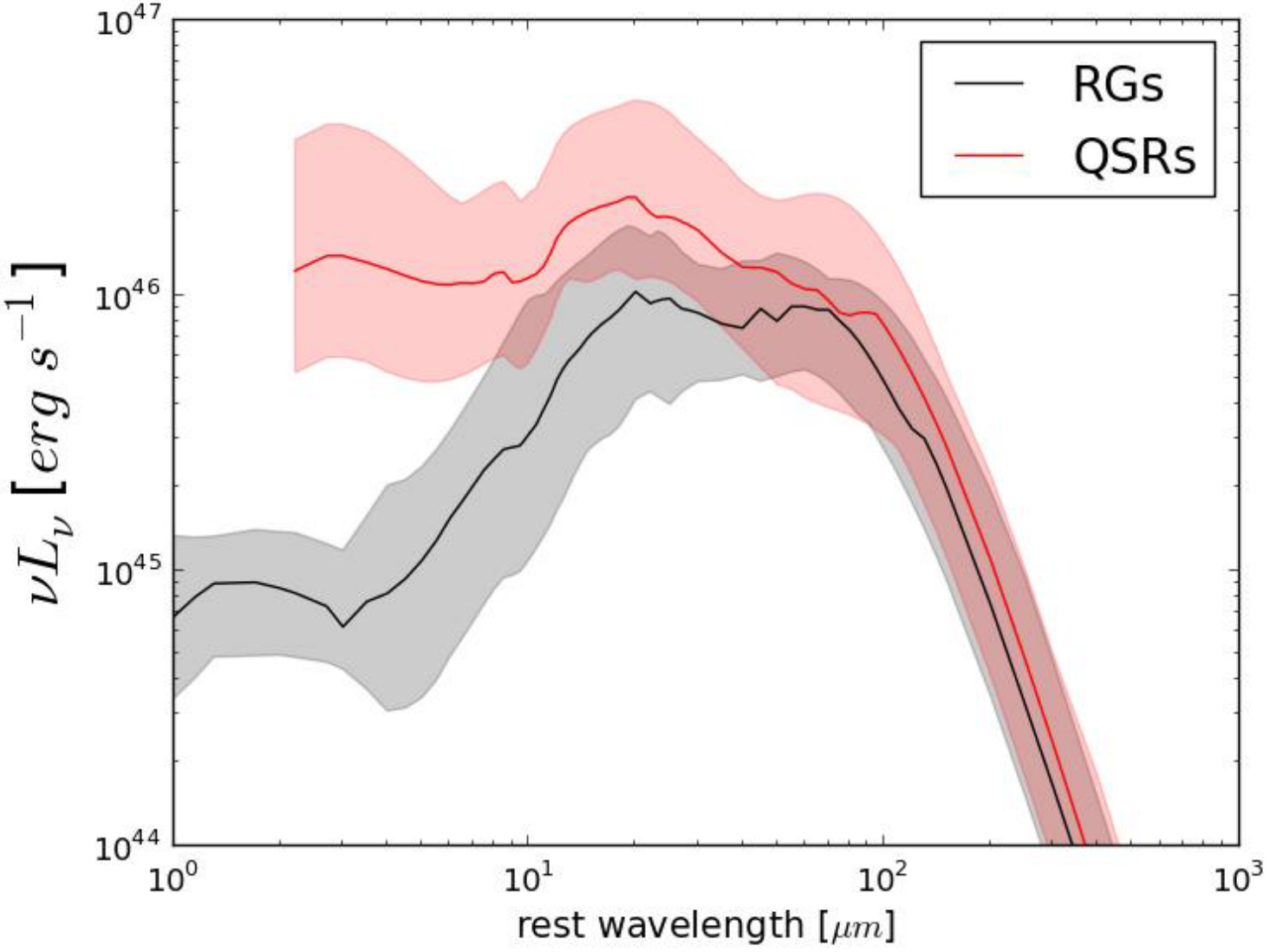
Following earlier indications of a high SFR, from 850μm and 350μm observations, the Herschel data permit quantification of that SFR.

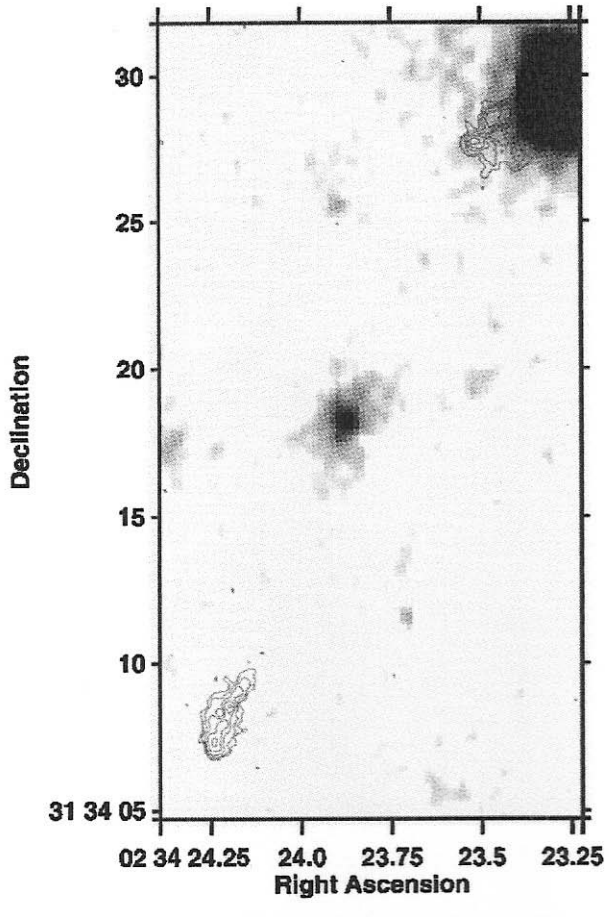
See AGN and star-formation AT WORK!

From 67%, 47%, 38%, 25%, and 15% detections at 70, 160, 250, 350 and 500 μm, and SED fitting, we find:



Podigachoski+, in prep.


RGs
QSRs
10^{47}
10^{46}
10^{45}
10^{44}
$\nu L_\nu\ [erg\ s^{-1}]$
10^0
10^1
10^2
10^3
rest wavelength [μm]



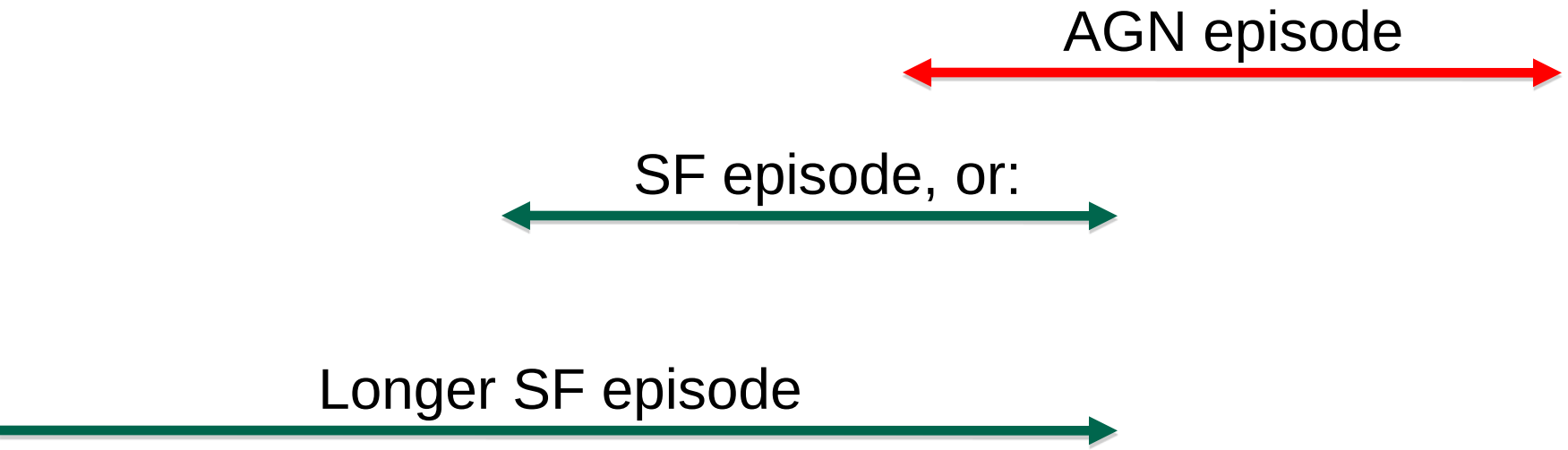
3C68.2 (z=1.6): 5x10^{11} M_{sun} host, and 190kpc radio source (i.e., AGN age of order 10^7 yr.

Can do order-of-magnitude computation:

SFR ~500 M_{sun}/yr during ~10^7 yr AGN event.

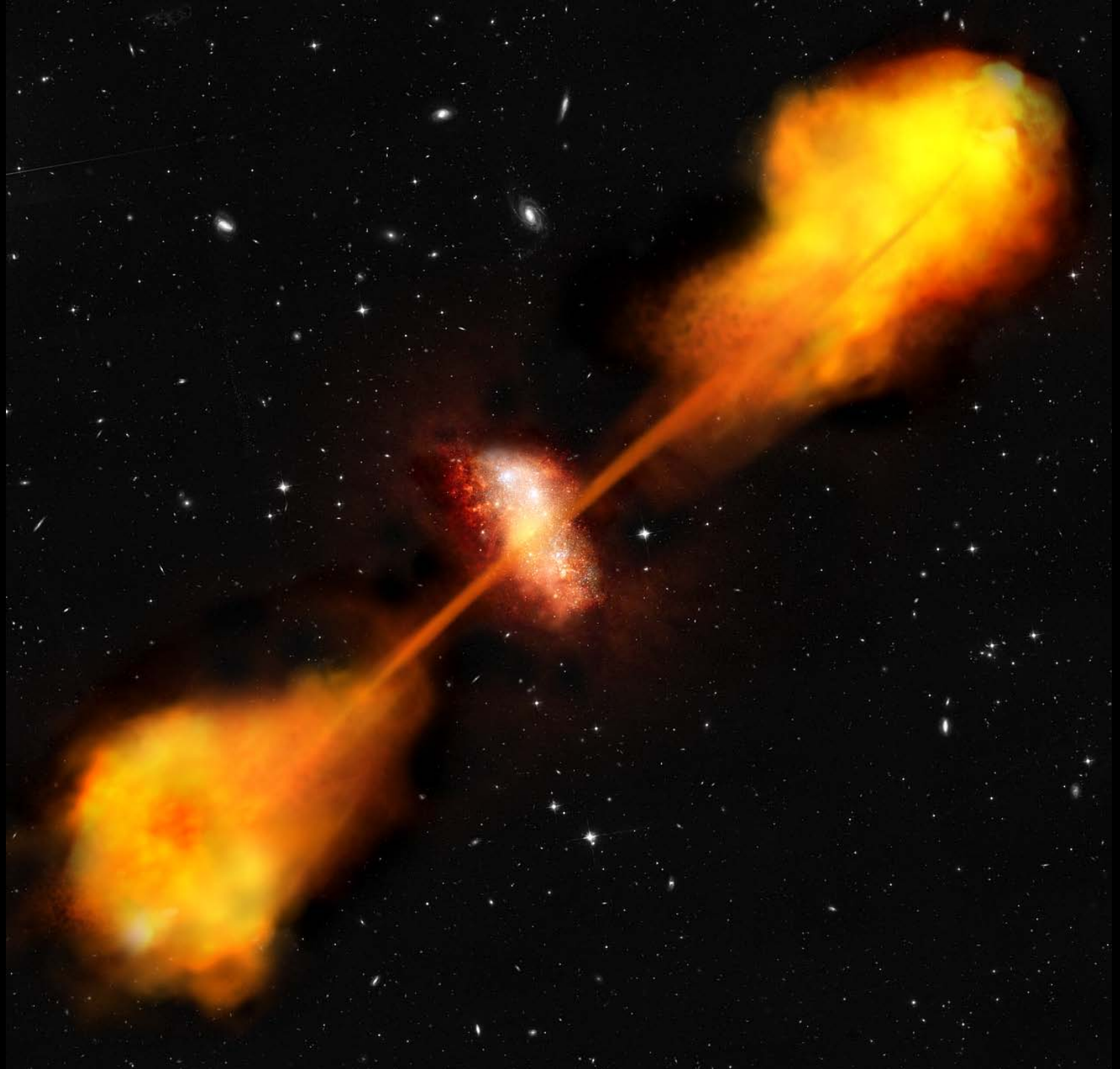
Implies formation of ~5x10^9 M_{sun} per event, so 10^2 AGN+SF events can form the host of 3C68.2 (provided coeval).

This takes ~10^9yr and builds in addition a 1x10^9 MBH, from dm/dt=1/yr, or ~5x10^{45} erg/s, which is 1/10 of the output of the AGN.

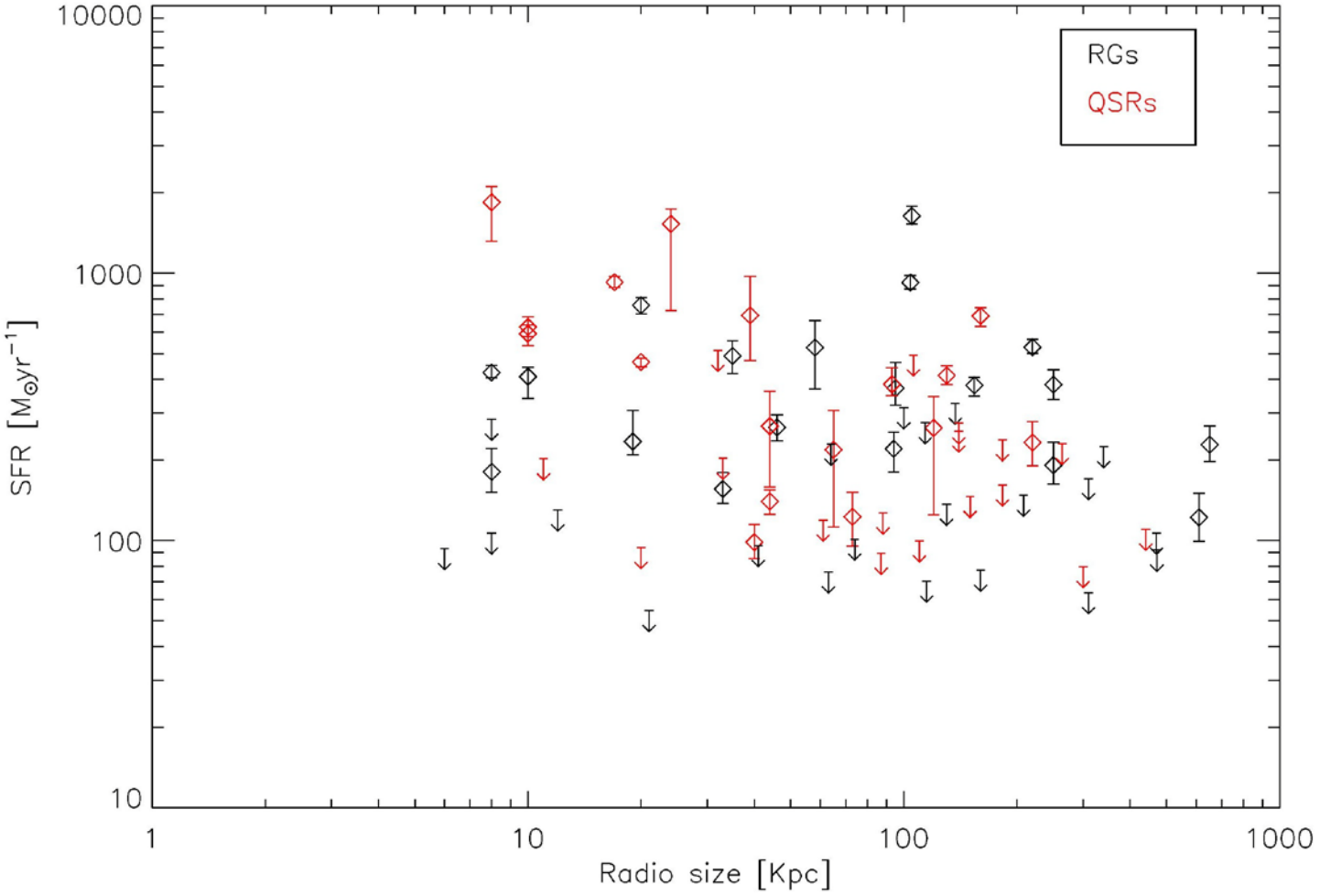


However, if SF commenced earlier and lasts 10^8y: get 10 AGN events @ 10 M_{sun}/yr accretion, or ~$5x10^{46}$ erg/s, the current AGN luminosity of 3C68.2 !

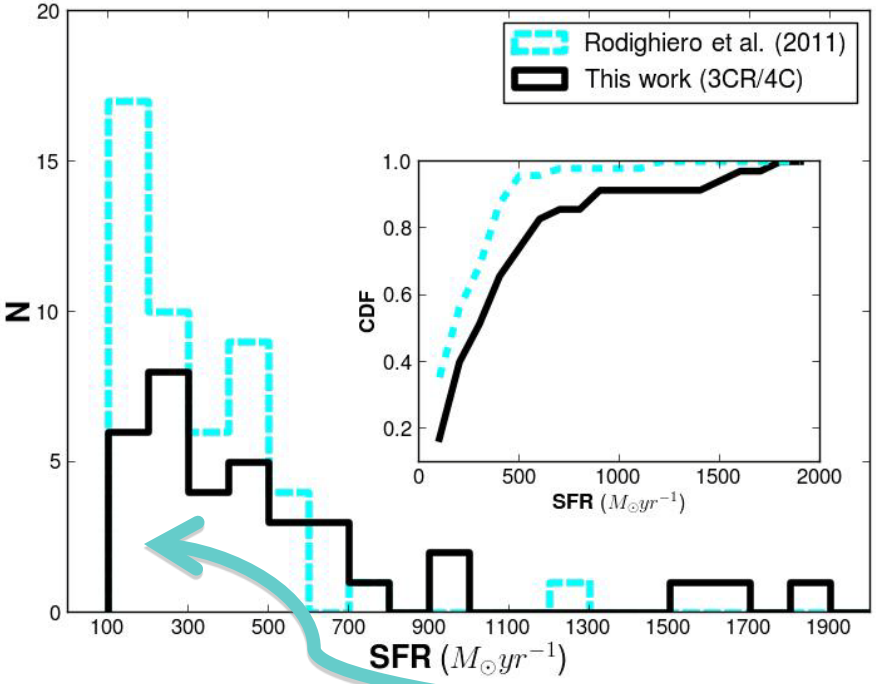
➔SEE EXTREME MASS BUILD-UP IN GALAXIES AND MBHs, FORCEFULLY AND EFFECTFULLY

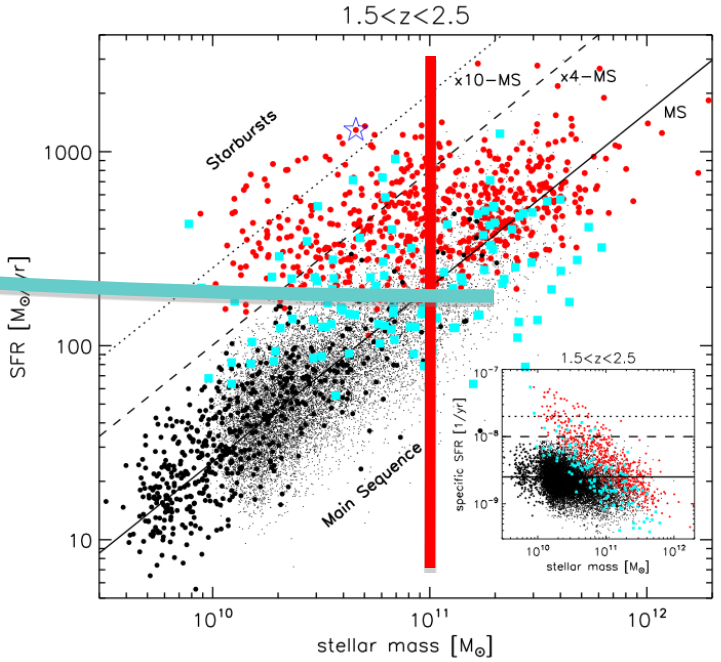


What about feedback and Main Sequence?

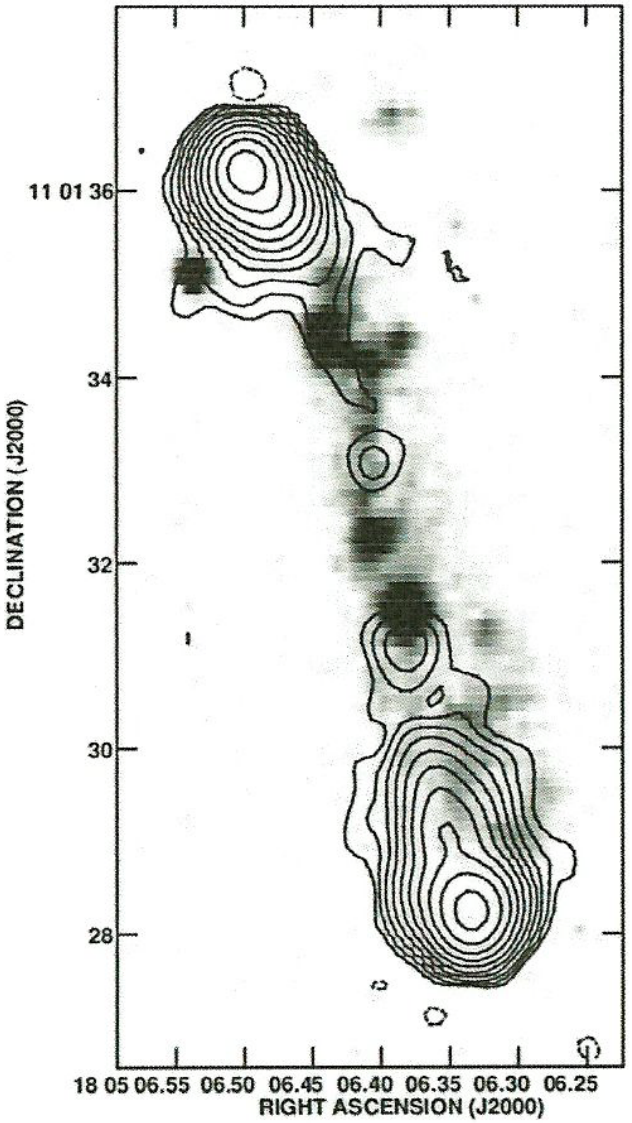


If any, it's positive feedback !

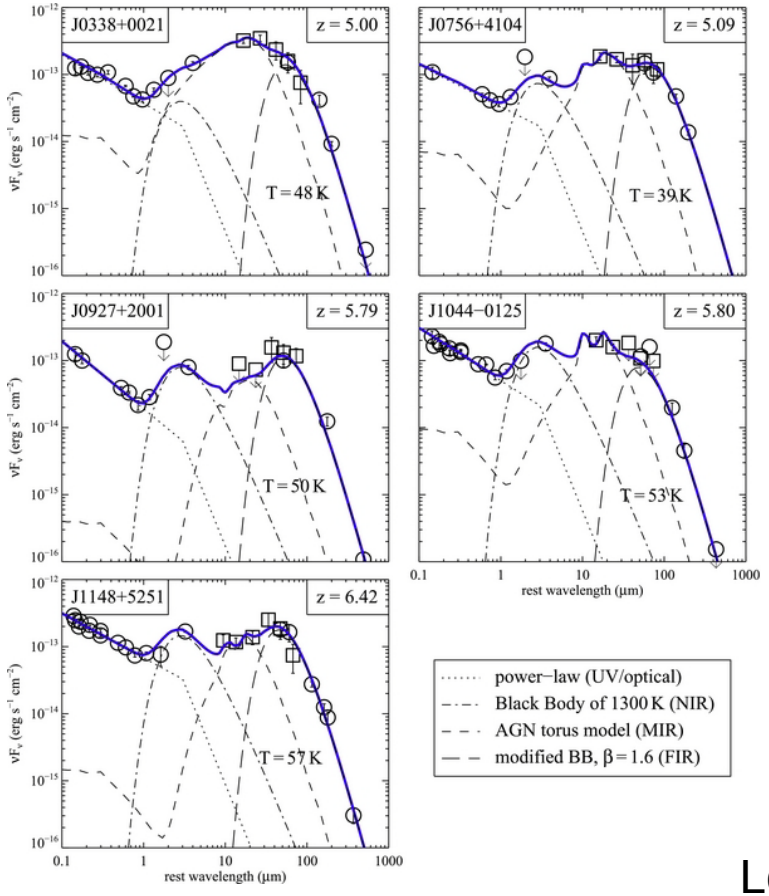




3C368 (et al.) have aligned uv emission, with strength anti-correlated with radio source size (= AGN age)



In line with Herschel and ALMA projects dealing with extreme z QSO hosts (mm-detected)



Leipski+13

REVIEWS OF MODERN PHYSICS VOLUME 35, NUMBER 4 OCTOBER, 1963

Evidence for the Occurrence of Violent Events in the Nuclei of Galaxies

G. R. Burbidge and E. M. Burbidge
University of California, La Jolla, California

and

A. R. Sandage
Mount Wilson and Palomar Observatories,
Carnegie Institution of Washington,
California Institute of Technology,
Pasadena, California

I. INTRODUCTION

It is generally believed that the vast majority of galaxies are massive condensations of matter which reached equilibrium configurations billions of years ago and have essentially remained unchanged ever since. Since they are in equilibrium under gravitational forces (magnetic forces are undoubtedly negligible in the bulk of the matter, which is condensed into stars), no significant departures from this equilibrium can be expected as the galaxy evolves in time, unless gravitational forces comparable in magnitude to the forces exerted in the gravitational potential of the galaxy are encountered. The only situation in which such effects will occur is when galaxies collide, and the most probable place of occurrence of collisions is in clusters.

It is therefore self-evident that unless outside influences come into play, once the equilibrium configuration is reached the distributions of mass and

Until recently this time scale has been the shortest which has been thought to be associated with galaxies taken as a whole, as far as structural changes or changes in rate of evolution or energy output are concerned. It is our purpose in this paper to describe a number of phenomena, all associated with the nuclei of galaxies, which may suggest that in these nuclei there may take place violent events manifested by a very large energy output and a time scale as short as 10^6 yr.

Some account of the phenomena described has been given previously in the literature, but we have considered it worthwhile to review all the evidence together.

II. OPTICAL DATA

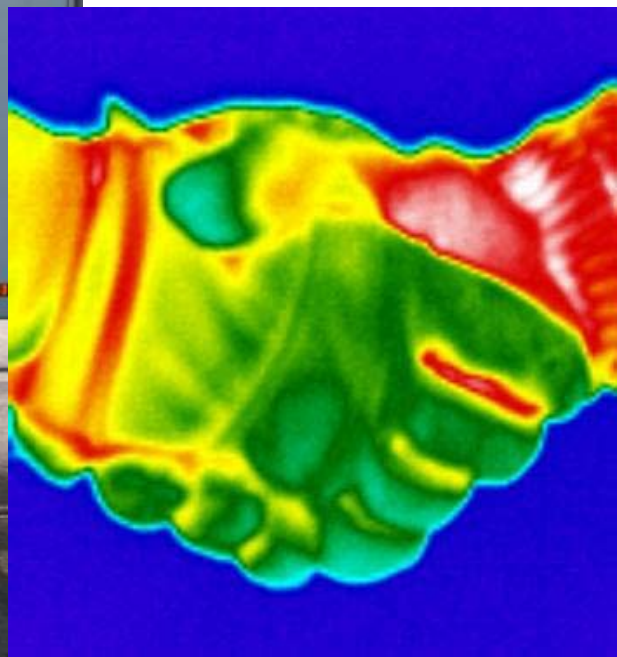
(1) Nuclei of Seyfert Galaxies

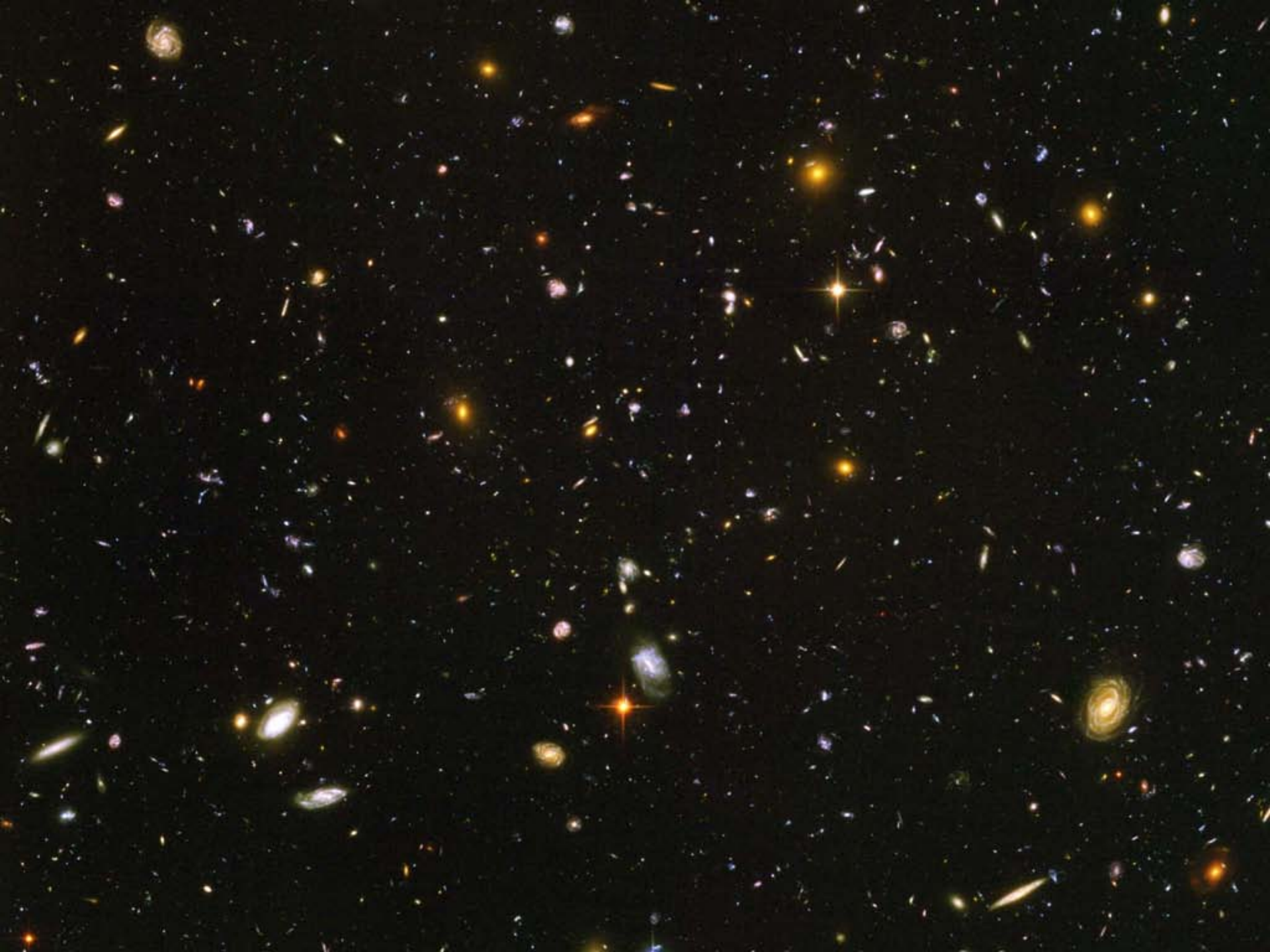
There are nine known galaxies which have nuclei satisfying the following criteria [eight of the twelve

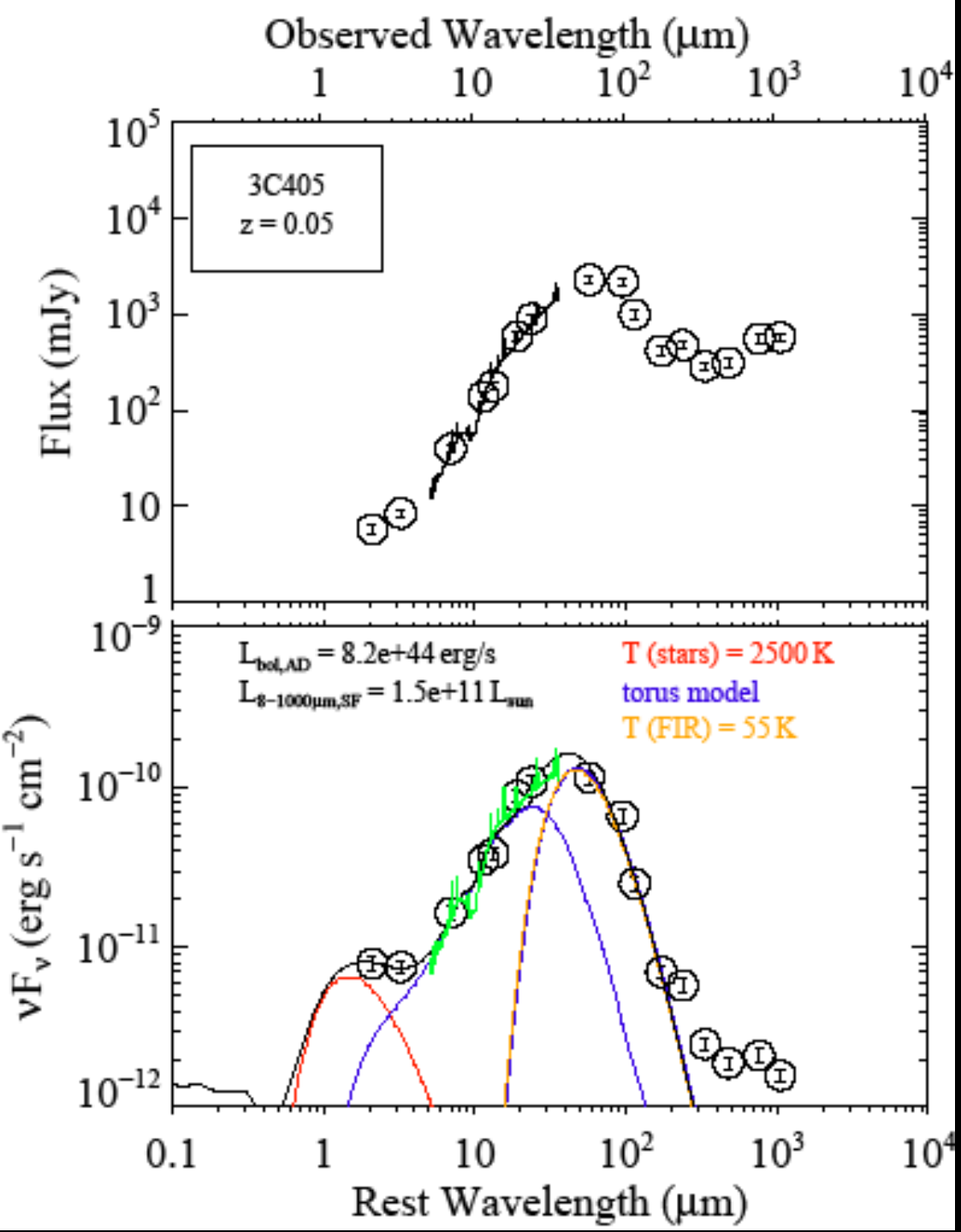
Half a century later: AGN (i.e., accreting MBHs) are simply basic (boring/exciting ..) ingredients of star-forming galaxies, throughout cosmic time.

William H. himself is pleased

and I thank you for your attention



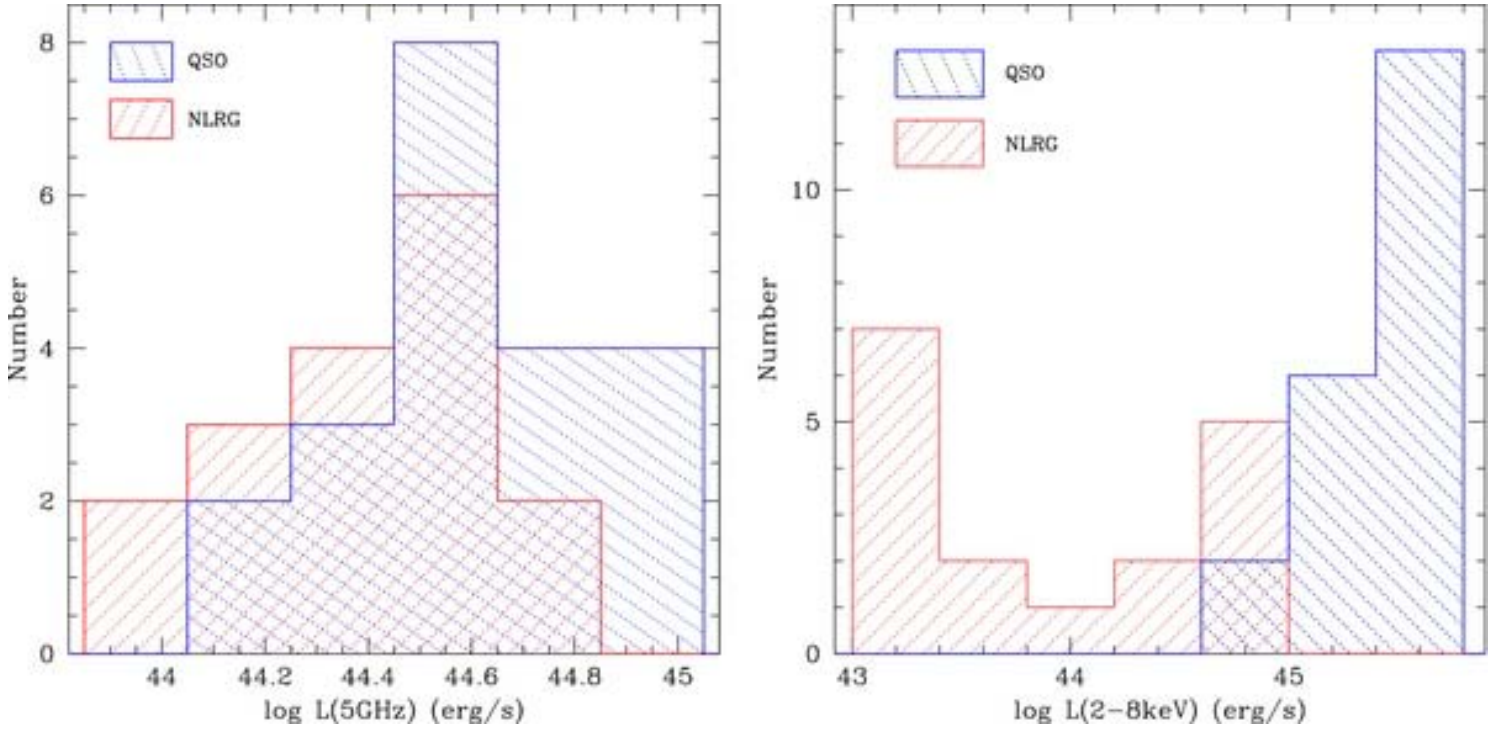




Cygnus A is obviously NOT the local high redshift radio galaxy ….

SED yields strength of AGN heated dust (circumnuclear ‘torus’) and extended star-formation heated dust, L_{AGN} and L_{SF}, in ~100 counterparts of Cygnus A

X-rays


QSO
NLRG
Number
log L(5GHz) (erg/s)
0
2
4
6
8
44
44.2
44.4
44.6
44.8
45
QSO
NLRG
Number
log L(2−8keV) (erg/s)
0
5
10
43
44
45

Formation of massive galaxies

- More compact in the past (e.g., Daddi+05)
- Gradual formation of outer parts (e.g., vanDokkum+10)
- Continuous accretion of (cold) gas, and mergers with small satellites (e.g., Conselice+13): dM/dt ~ 100 at redshifts 1.5 - 3