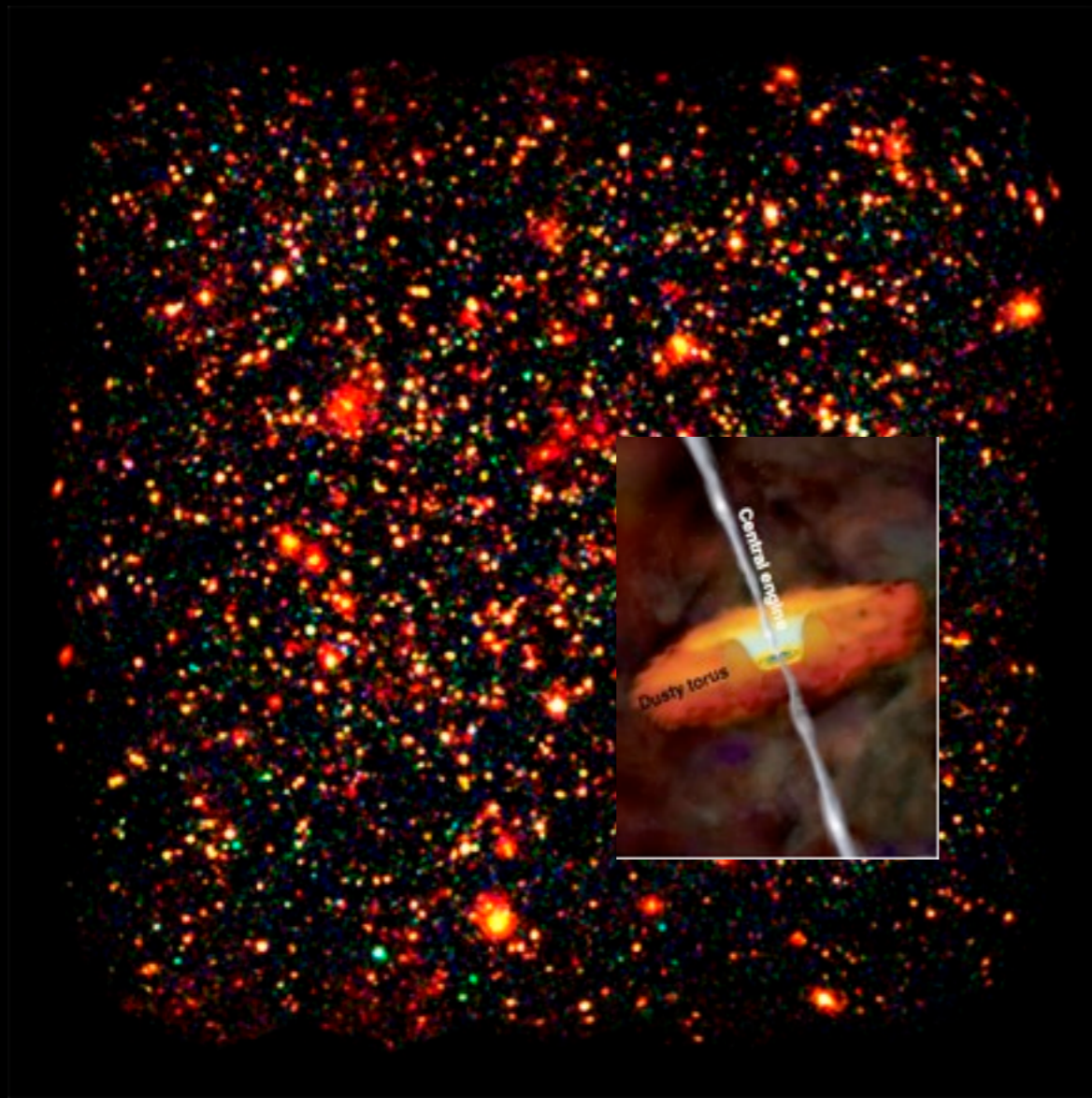# Starburst-AGN connection: a mutual relation?

Marcella Brusa

Max-Planck Institut für Extraterrestrische Physik

Garching, Germany

XMM view of the COSMOS field

"The Starburst-AGN connection under the multiwavelength limelight"
ESAC (Villafranca de Castilla) / September 14-16, 2011

Monday, September 26, 2011

Observational evidences of a mutual relationship (1)

Star formation (SF)	AGN
1) traces growth of stellar mass 2) all galaxies assembled their masses through episodes of SF (starbursts)	1) traces growth of BH mass ($>10^6 M_{sun}$) 2) all SMBH assembled their mass through accretion during AGN phase (SMBH are present in almost all galaxies) all galaxies went through an AGN phase

Observational evidences of a mutual relationship (1)

Star formation (SF)

1) traces growth of stellar mass

2) all galaxies assembled their masses through episodes of SF (starbursts)

AGN

1) traces growth of BH mass ($>10^6$ M_{sun})

2) all SMBH assembled their mass through accretion during AGN phase

(SMBH are present in almost all galaxies)
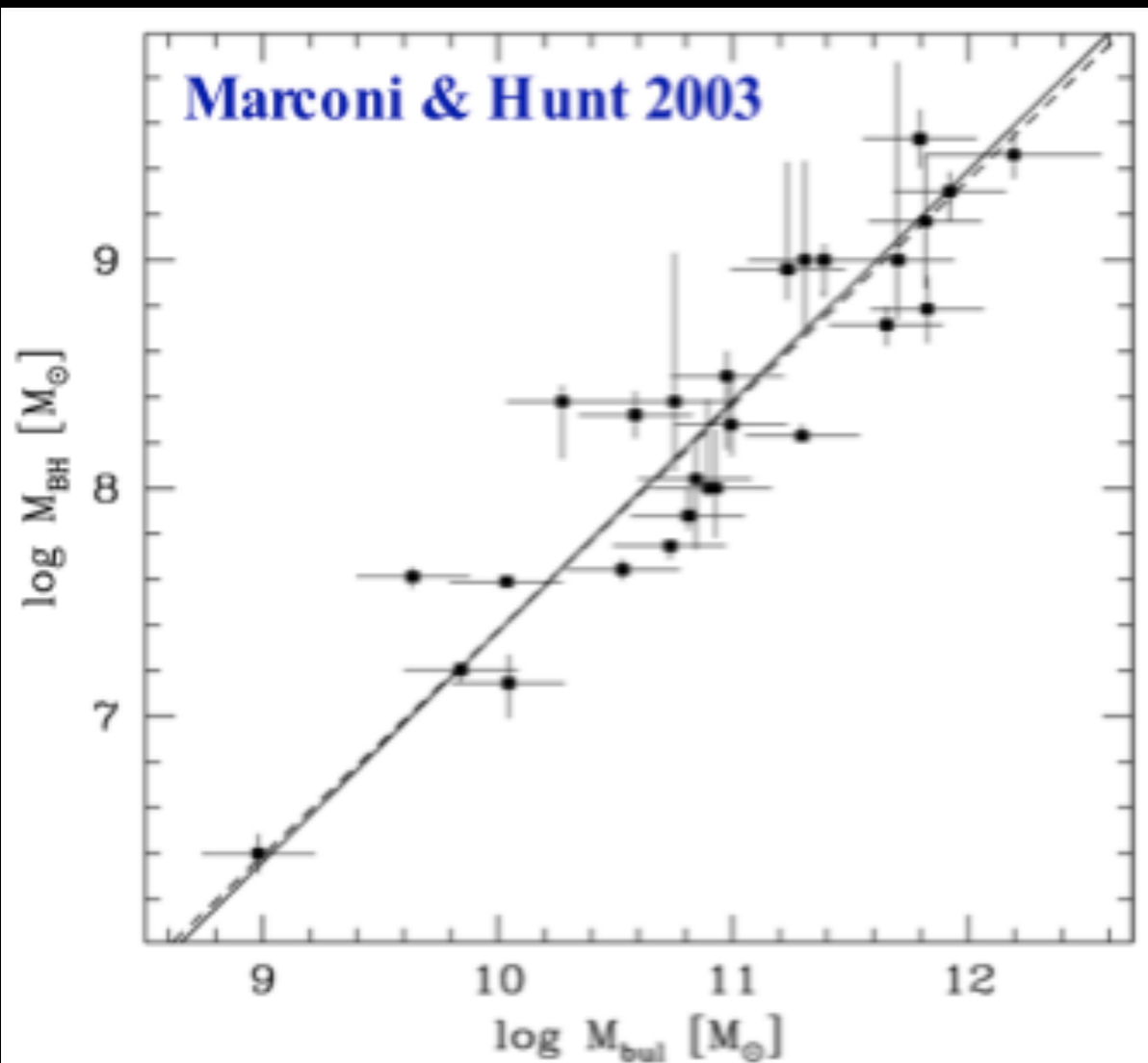
all galaxies went through an AGN phase

Marconi & Hunt 2003

First evidence of Starburst-AGN connection:

BH mass depends on stellar mass (local scaling relations)

see also
Ferrarese & Merritt 2000, Gebhardt et al. 2000
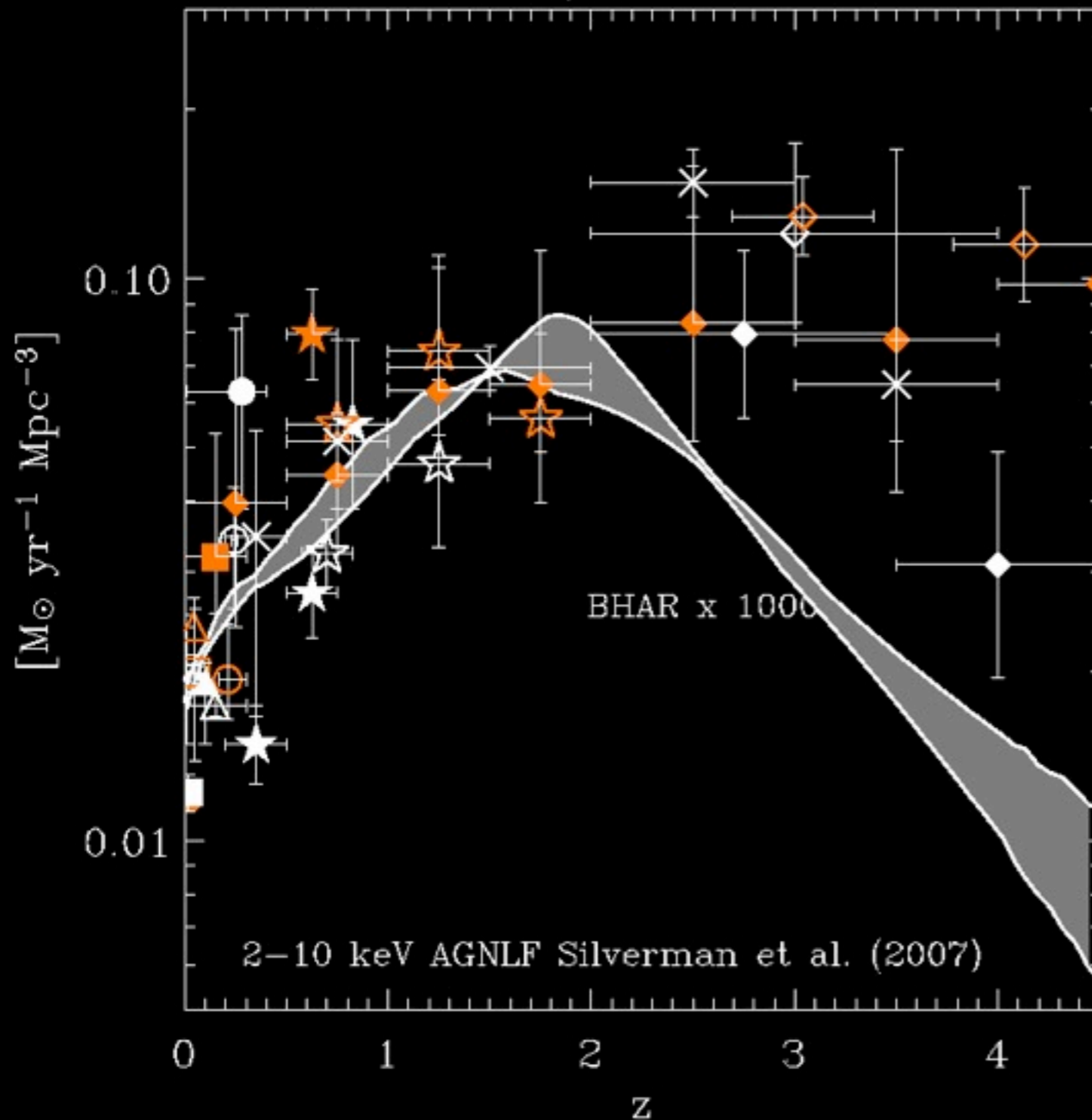Haering&Rix 2004, Greene et al. 2007
Gultekin et al. 2009
(but see Jahnke & Maccio' 2011, Cen 2011)

Observational evidences of a mutual relationship (2)

$\eta = 0.08$

BHAR x 1000

2–10 keV AGNLF Silverman et al. (2007)

(integral) SMBH growth traces (integral) SFR

SMBH growth = from XLF of AGN (modulo uncertainties in N_H distribution vs. z and Compton Thick sources)

SF growth = from deep NIR and optical surveys (data: Hopkins & Beacon 2006)

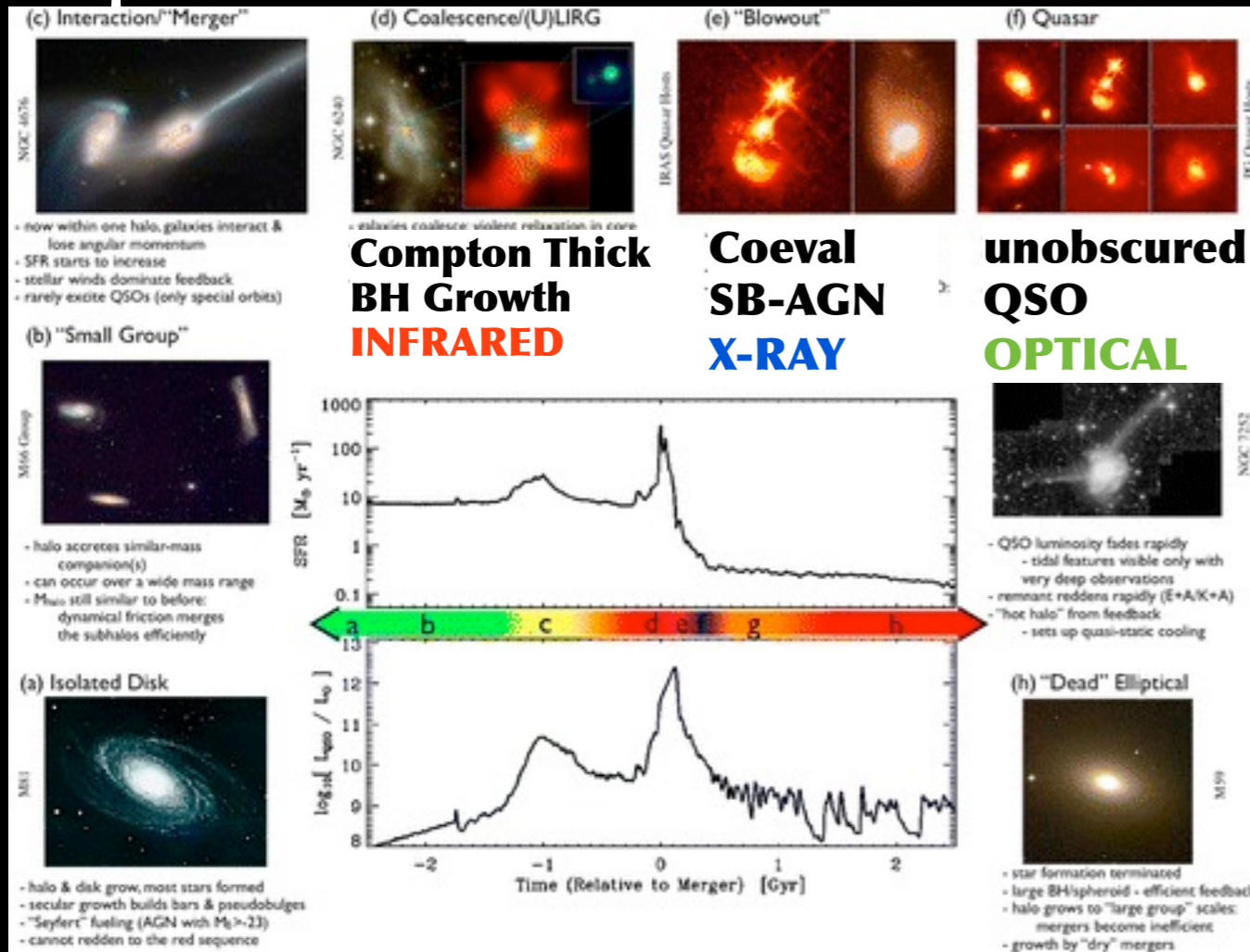See e.g. Merloni 2004; Marconi et al. 2004; Shankar et al. 2007; Merloni & Heinz 2008

Observational evidences of a mutual relationship (3)

SF downsizing

AGN downsizing

Thomas et al. 2005
De Lucia+2006

La Franca et al. 2005

Cosmic "downsizing"

the larger the faster (Cowie et al. 1996):

"... galaxy formation took place in "downsizing", with more massive galaxies forming at higher redshift.."

Fiore,Brusa+2003 (HELLAS2XMM)
Ueda+03; Barger+05; Hasinger+05; Silverman+05, Bongiorno+07, Della Ceca+08, Ebrero+09 etc. - but see Aird et al. 2010
more luminous AGN had the peak of activity at earlier redshifts

Observational evidences of a mutual relationship (4)

- **correlation** between AGN and FIR luminosity (e.g.Netzer+2007, Lutz +2008, Netzer 2010)

- **correlation** between AGN luminosity and PAH strength (e.g. Schweitzer +2006, Lutz et al. 2008)

- We **observe** simultaneous SF and AGN activity in bright local AGN and QSO (e.g. some well-known objects studied in details, e.g. NGC 1068, NGC 6240, Mrk231,Arp299, Circinus...)

- [posters and talks all over the workshop]

mergers scenario
(ULIRGs-QSO sequence)

Hopkins et al. 2008

(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

Compton Thick BH Growth INFRARED

(e) "Blowout"

Coeval SB-AGN X-RAY

(f) Quasar

unobscured QSO OPTICAL

(b) "Small Group"
- halo accretes similar-mass companion(s)
- can occur over a wide mass range
- M$_{BH}$ still similar to before: dynamical friction merges the subhalos efficiently

- 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$_{BH}$>-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

(e.g. Sanders et al. 1988, Silk & Rees 1998, Granato et al. 2004, Di Matteo et al. 2005, Hopkins et al.2006-2009, Croton et al. 2006, Fontanot et al. 2006, De Lucia et al. 2006, Sijacki et al. 2007, Menci et al. 2008, Marulli et al. 2009)

Early on

Mergers between gas rich galaxies drive gas which fuel both SF and BH activity;

Violent starbursts episodes (ULIRGS);

Heavily obscured BH growth

When galaxies coalesce

Accretion peaks;

SMBH becomes X-ray and optically "visible"

QSO phase follow, AGN winds blow out gas

Later times

SF & BH accretion quenched;

Dead quasars in red galaxies (passive evolution)

AGN co-evolutionary models vs. Unified models
(definition of obscured AGN: "time" critical vs. "orientation")
BH growth and SF **simultaneous** --> feedback from AGN

Is this valid for all systems?
(Starburst-AGN sequence)
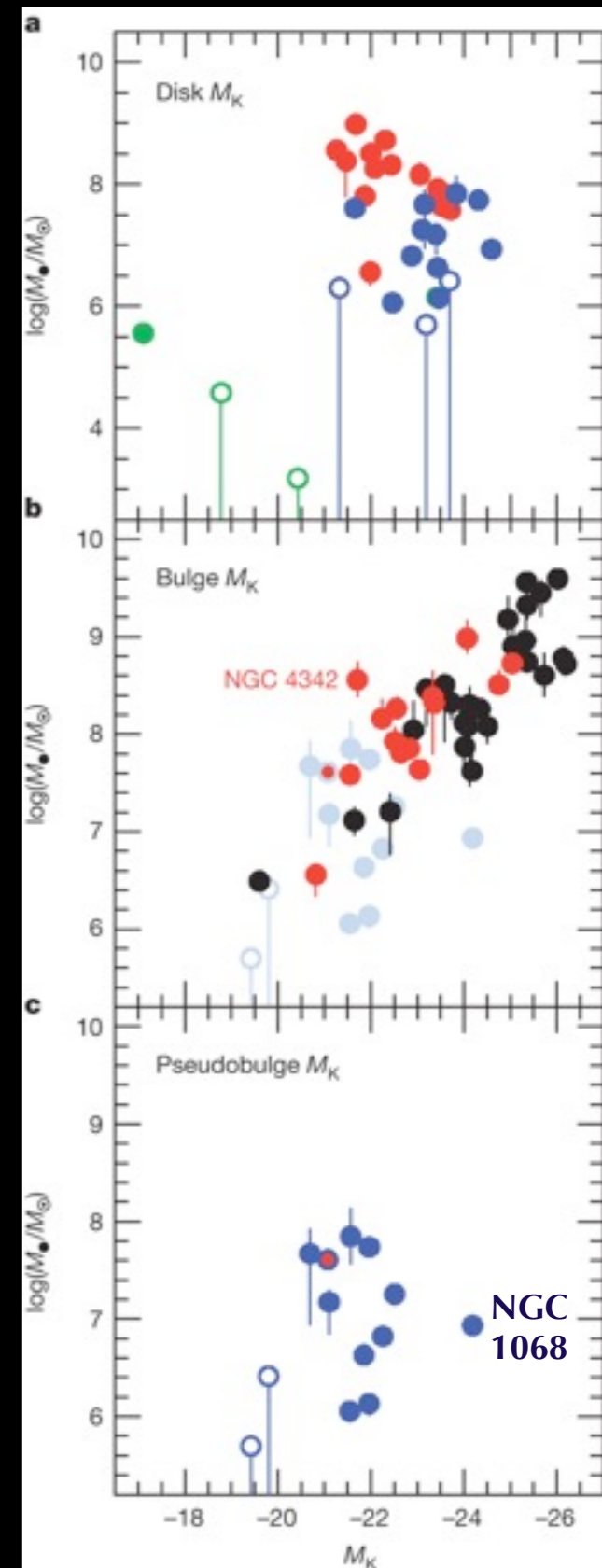
Kormendy et al. 2011

A population of galaxies evolved without mergers does clearly exist (**disks are observed at z~2**; e.g. Genzel+2006, 2008; **see also yesterday ESA/Herschel press release: Elbaz+11, Rodighiero+11**)

no correlation between M_{BH} and disk or pseudobulge properties (Kormendy et al. 2011; see also Graham et al. 2010)

Stochastic/secular accretion can **explain some classes of low-L AGN (NLS1)** observed at low-z (see also Davies talk)

Dichotomy in formation history of galaxies

mergers vs. secular

(weak) activity driven stochastically by local processes (galaxies encounters, inflow, disks/bars instabilities etc.; Croton+2006, Ciotti&Ostriker, Cen 2011, Bournaud+2011, Di Matteo+2011)

Expectations and key tests/observable

1) Correlation SFR - AGN luminosity?

expected in mergers scenarios - AGN regulate the SB **(see Lutz and Mullaney talks friday!)**
not expected if SB and AGN are nocoeval (Cen 2011)

2) enhanced SFR in AGN hosts? (and AGN colors)

expected in mergers scenarios, but it is time--dependent (expected pre and during the merger, not post-merger); luminosity dependence?

3) AGN hosts morphologies

should be different in the merger (elliptical or disturbed systems) or secular (disks) scenarios

4) Difference in SFR between Type 2 and Type 1

obscured AGN at high-z are expected to be more starforming than unobscured AGN
(see tomorrow morning session!)

5) are we able to disentangle among positive (enhance SF) and negative (stop SF) AGN feedback? Evolution effects?

AGN power may be greater than binding energy of host galaxies and may provide necessary feedback to stop star formation; crucial role of mm/ALMA observations
(see Maiolino talk and friday session!)

Expectations and key tests/observable

1) Correlation SFR - AGN luminosity?

expected in mergers scenarios - AGN regulate the SB **(see Lutz and Mullaney talks friday!)**
not expected if SB and AGN are nocoeval (Cen 2011)

2) enhanced SFR in AGN hosts? (and AGN colors)

expected in mergers scenarios, but it is time--dependent (expected pre and during the merger, not post-merger); luminosity dependence?

3) AGN hosts morphologies

should be different in the merger (elliptical or disturbed systems) or secular (disks) scenarios

4) Difference in SFR between Type 2 and Type 1

obscured AGN at high-z are expected to be more starforming than unobscured AGN
(see tomorrow morning session!)

5) are we able to disentangle among positive (enhance SF) and negative (stop SF) AGN feedback? Evolution effects?

AGN power may be greater than binding energy of host galaxies and may provide necessary feedback to stop star formation; crucial role of mm/ALMA observations
(see Maiolino talk and friday session!)

Tools: (hard) X-ray surveys

most complete (modulo Compton Thick sources)

least contaminated (normal galaxies and stars emerge only in deepest exposures)

catch AGN in blowout and QSO phase

(e) "Blowout"	(f) Quasar
Coeval SB-AGN **X-RAY**	obs/unobs QSO **X-ray/OPTICAL**
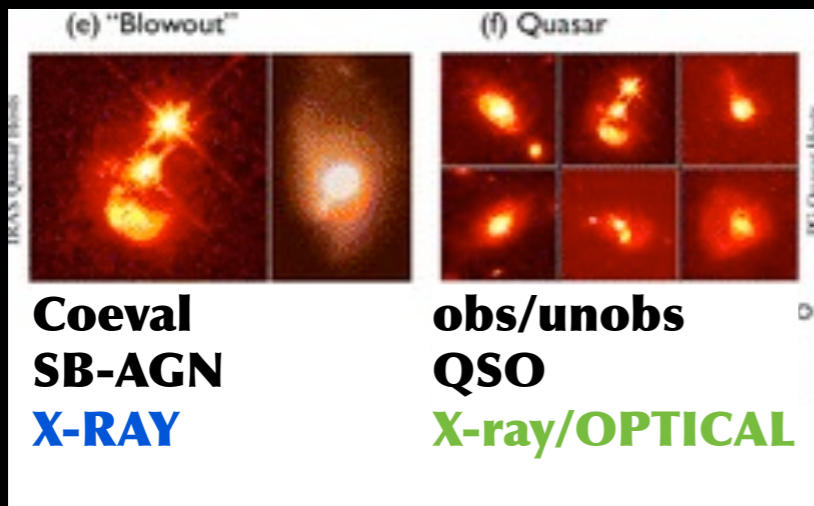
<u>Multiwavelength coverage</u> to assure identification, redshift determination, SED studies, host galaxy properties, and alternative AGN selection (e.g. Compton Thick census; **see Donley/Vignali talks**)

COSMOS field, 2 deg² (Scoville+07)
XMM 1.55 Ms (Hasinger+07, Cappelluti+09, Brusa+10)
Chandra 1.8 Ms (Elvis+09, Civano+in prep)
down to ~1e-15 cgs, ~1800 objects soft 0.5-2.0 keV
medium 2.0-4.5 keV
hard 4.5-10.0 keV
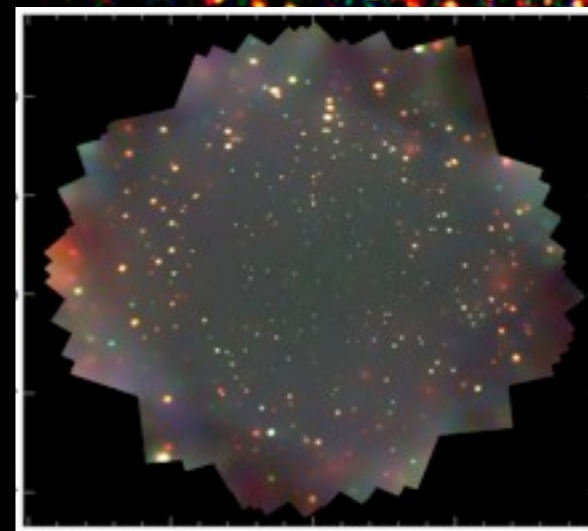
CDFS Chandra 1-2-4Ms
XMM 3 Ms
~0.1 deg2, ~4e-17 cgs
300-750 objects
(Giacconi+2002, Alexander +2003, Luo+ 2008,10, Xue +2011, Comastri+2011)

Ony two among the many (~40) XMM & Chandra surveys in russian-doll style

All wavelengths, very deep coverage available

Star formation in AGN hosts

Brusa et al. (2009) - obscured AGN in CDFS   logLx ~43
Lusso et al. (2011) - Type 2 AGN in COSMOS   logLx~43.5
Mainieri et al. (2011) - QSO2 in COSMOS   logLx > 44
Xue et al. (2010) - AGN in GOODS fields   logLx>42

Santini et al. (2011) - PEP/Herschel data of GOODS+COSMOS AGN

Host/AGN decomposition
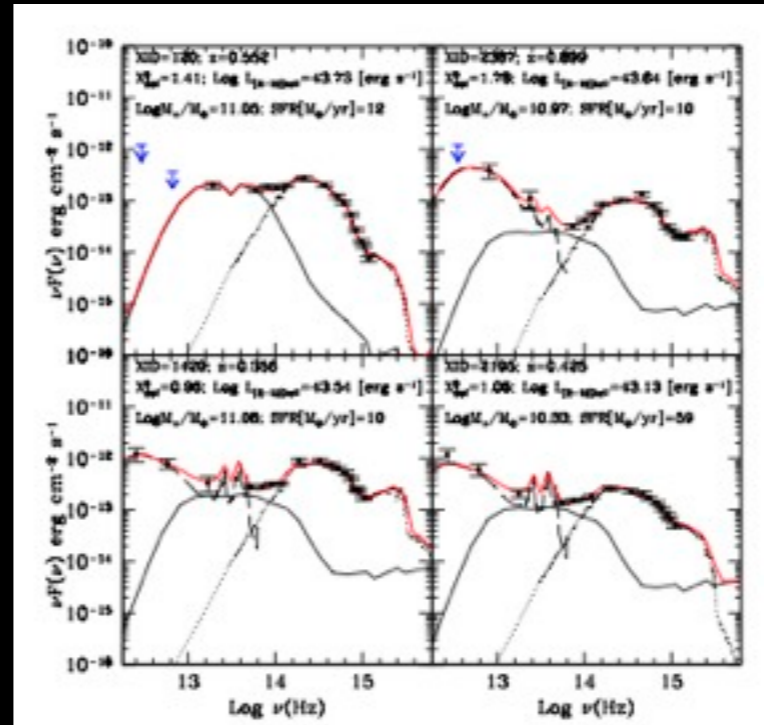
Full XMM-COSMOS sample (~1600 objects, Brusa+2010)

(particularly) important for moderate & high-lum obscured QSO and unobs AGN (all lum)
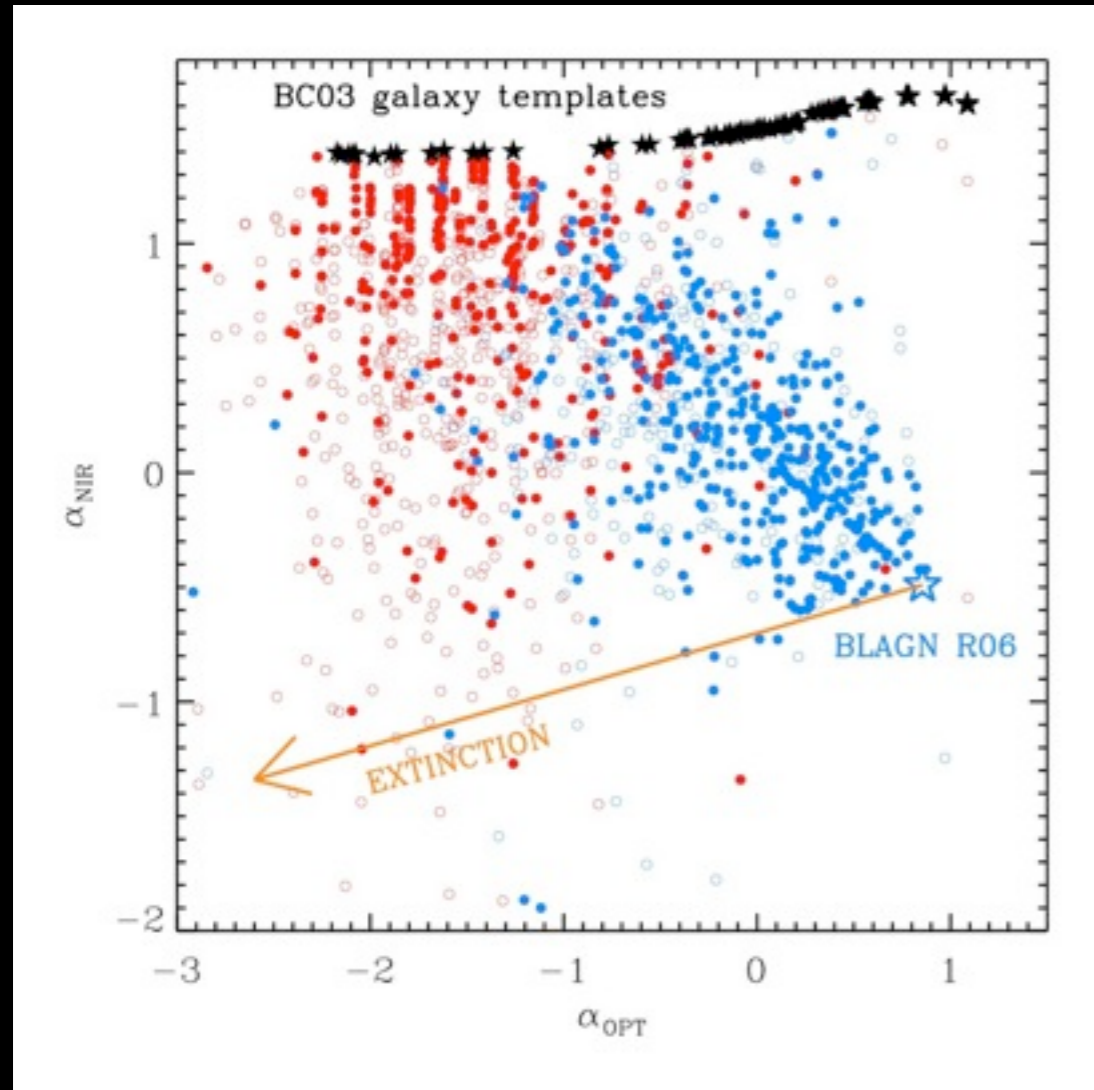
Lusso+2011 (Type2)   **Bongiorno+in prep (full XMM)**
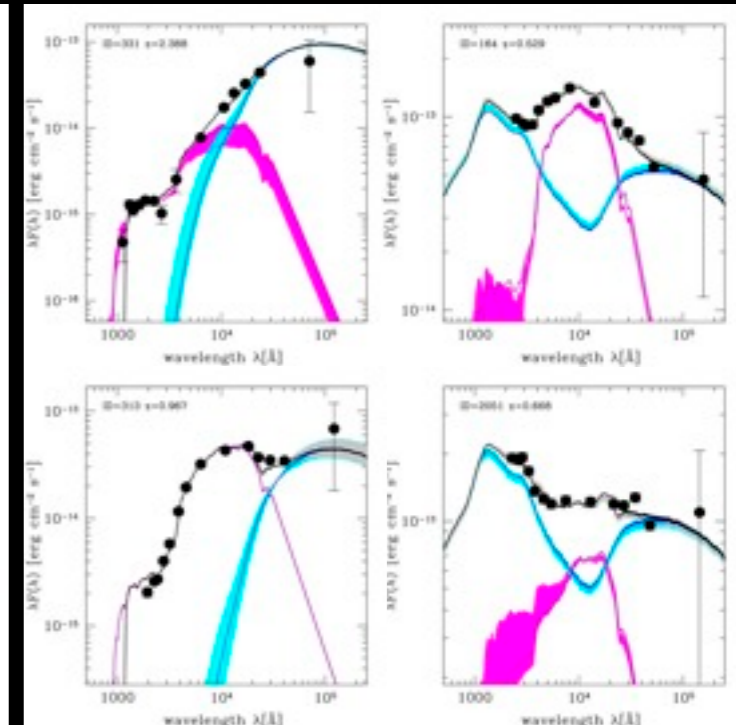
see also Merloni+2010 (BL AGN) Bongiorno et al. 2011 (full XMM)
Pozzi+2007,2010; Gruppioni+2010; Santini+2011 - **see Feltre talk!**

(adapted from Hao+2010)

Most of the SEDs can be explained as a combination of a **pure AGN**, **extinct** and/or contaminated by the **host galaxy**

Fact:
(Without Herschel information) Multiple components SED fitting needed (AGN + host galaxy) to get the physical parameters

Obscured AGN: colors

Brusa+2009
(obscured AGN in CDFS, <Lx>~43)
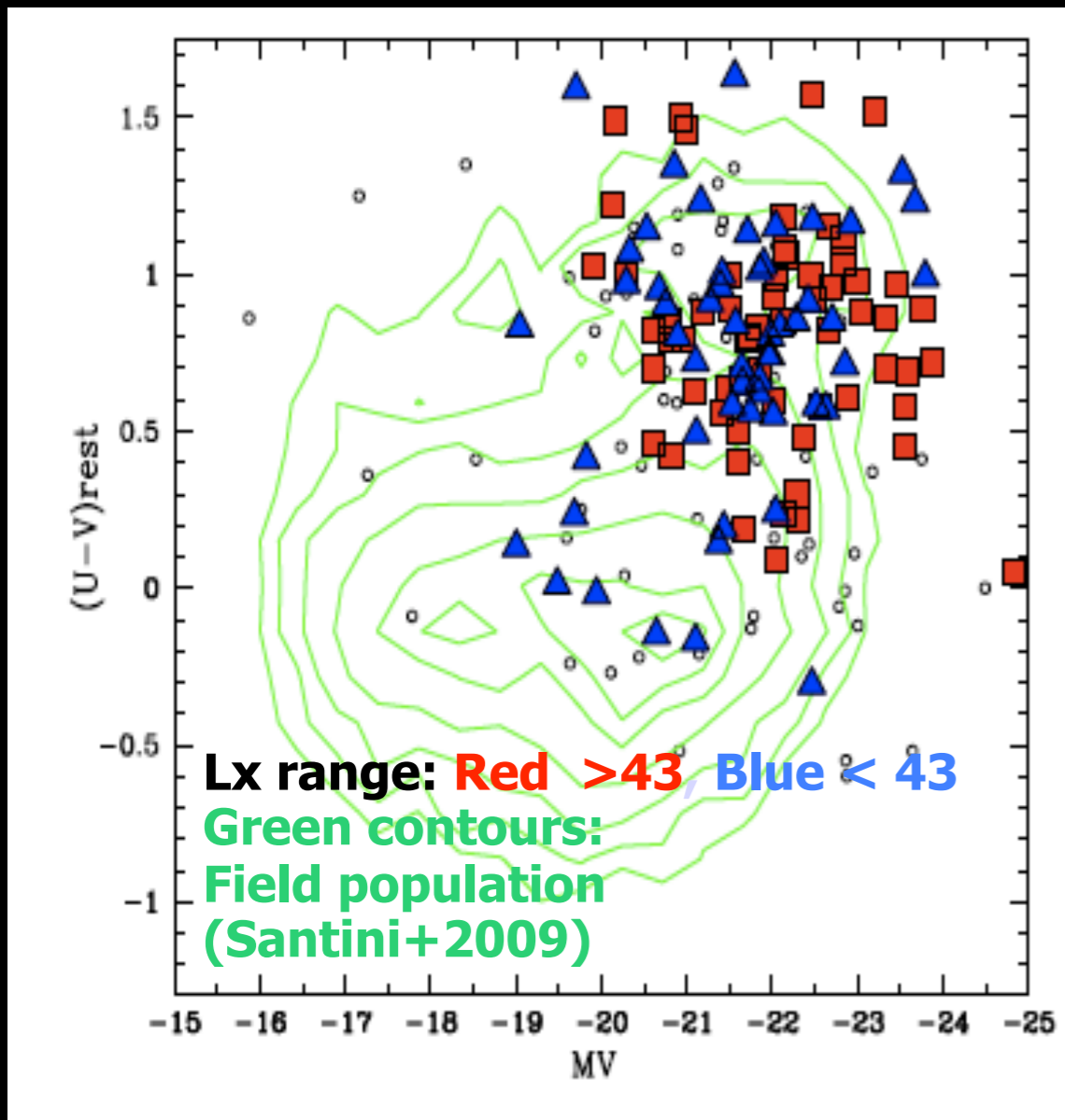
Xue+2010 (obscured AGN in CDFS, <Lx>~43)

Lx range: **Red** >43, **Blue** < 43
Green contours:
Field population
(Santini+2009)
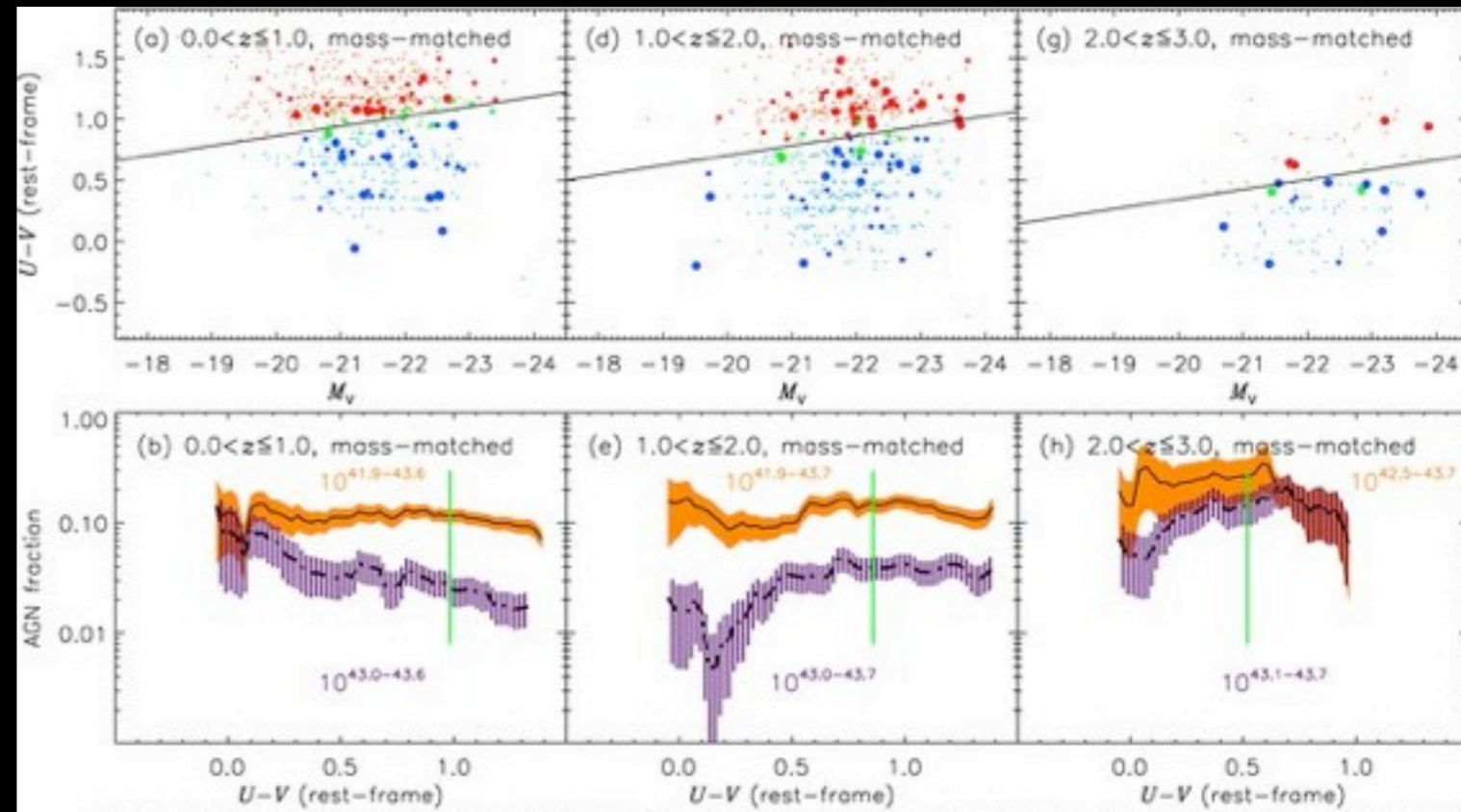
Importance of mass-matched parent samples:
AGN have expected colors of galaxies of their mass
(see also Cardamone+2009, Lusso+2011)

Field galaxies: Two distinct populations: red sequence and blue cloud (early type and SF galaxies)

AGN: (X-ray selected) AGN populate the "green valley" or "red sequence" (see Kauffmann+03, Nandra +05, Silverman+08, Schawinski+10) at almost all z they are red, optically luminous and massive

Fact:
obscured AGN are RED, but not particularly redder or luminous than inactive galaxies of same mass

Obscured AGN: SFR

Brusa+2009
(obscured AGN in CDFS. <Lx>~43)

Blue <43,
Red > 43
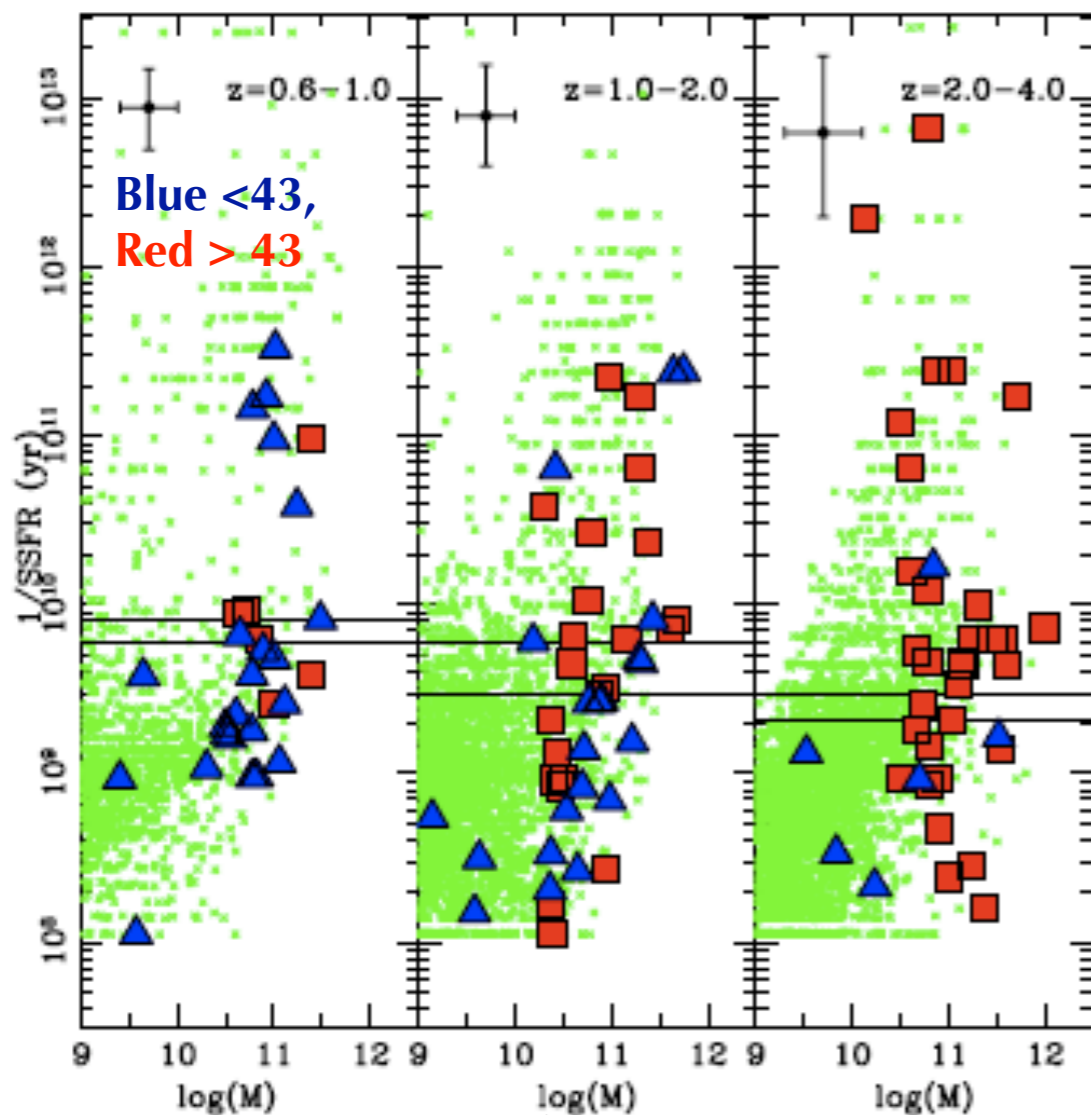
Masses and SFR from Santini+09

Lusso+2011
(Type2 AGN in COSMOS, <Lx>~43.5)
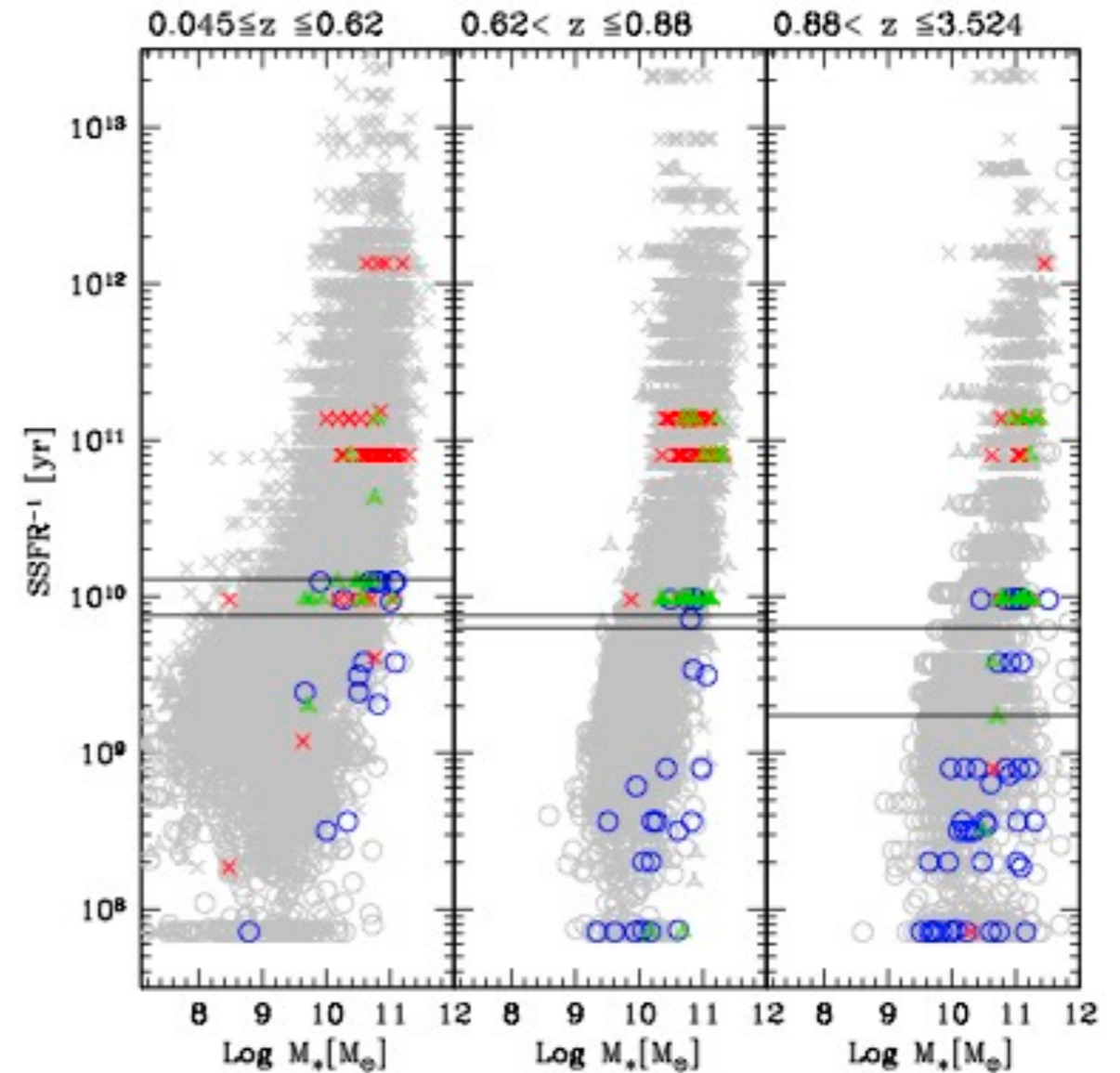
Fact:
50% X-ray selected obscured AGN are actively forming stars
(>20 Msun/year or 1/SSFR<t_Hubble), at almost all redshifts
but they are not (all) ULIRGS/Starbursts galaxies

Obscured QSO: SFR

Same level of starformation for "active" (AGN) and "inactive" (SF) galaxies

QSO2 hosts follow the tight correlation between SFR and M_* of blue star-forming galaxies (e.g. Noeske+07; Daddi+07; Elbaz+07; Rodighiero+10 / **Herschel**)

"Passive" population also present

Fact:

Obscured AGN associated to SF galaxies **do not scatter significantly off the main sequence of SF galaxies**
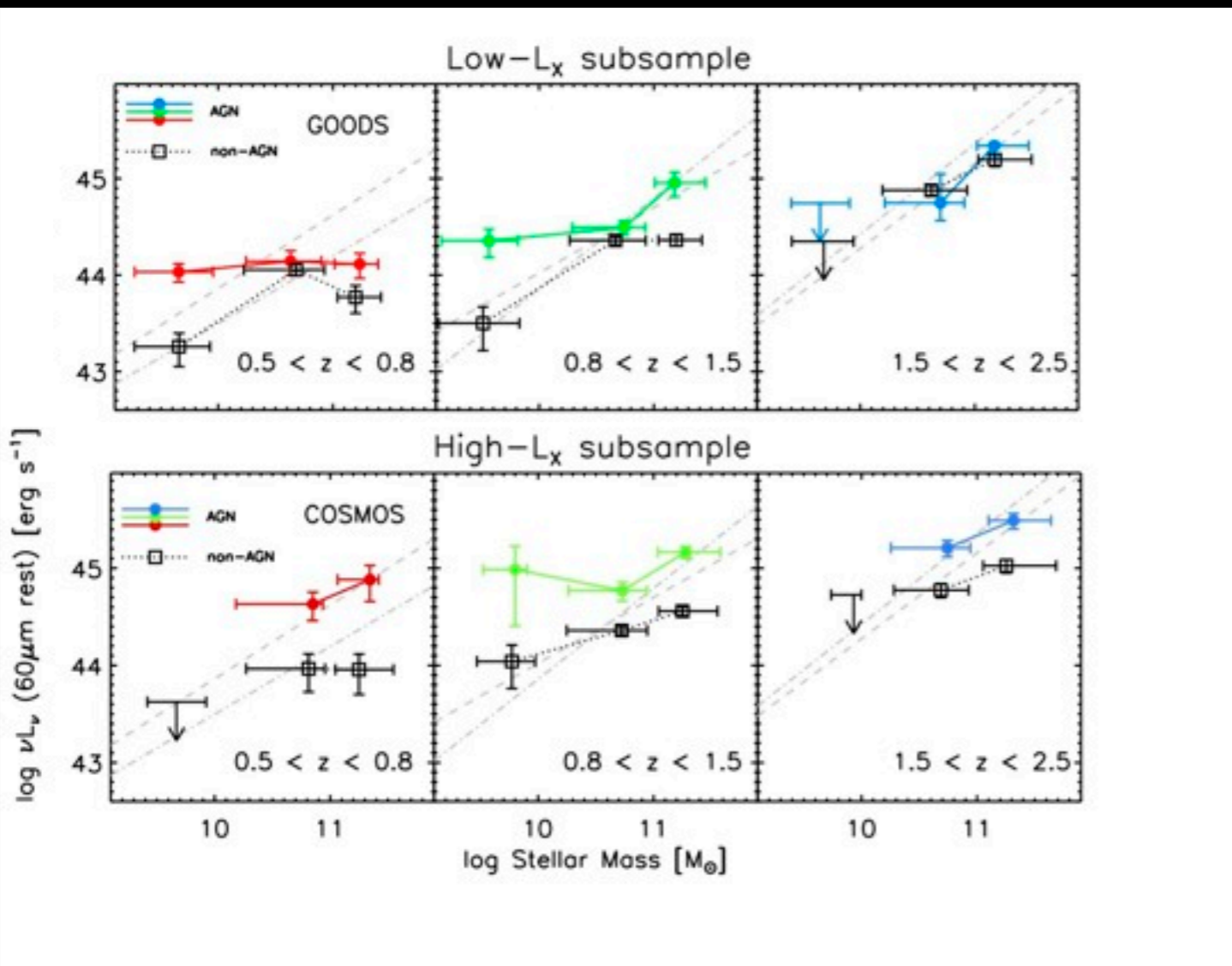
Mainieri et al. 2011 (QSO2 in COSMOS, Lx>44)
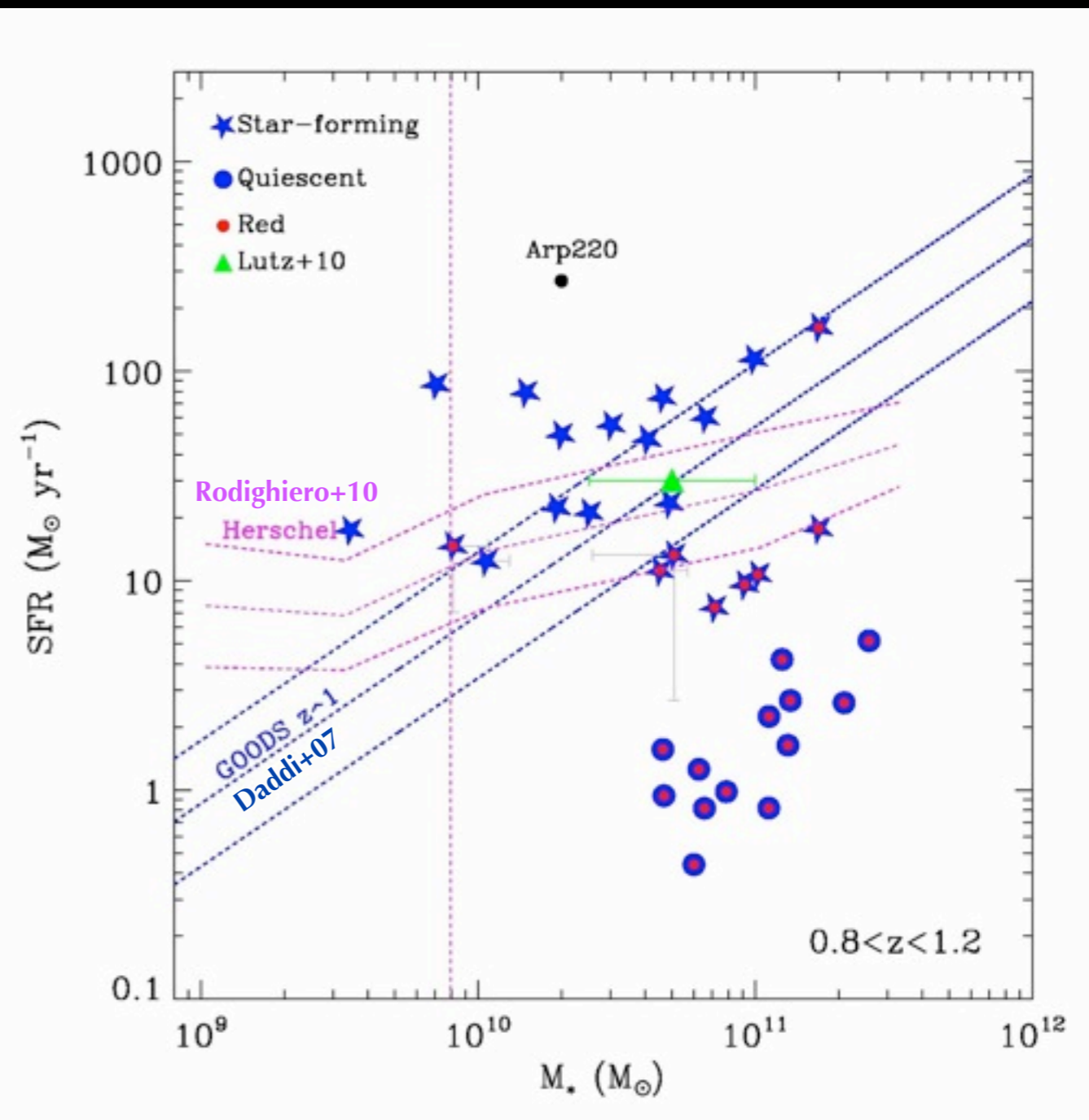
See Vincenzo Mainieri talk on Friday!

Enhanced SFR in AGN hosts?

Santini+2011 (GOODS & COSMOS)

Evidence for enhancement:
- GOODS (low-Lx):
SFR in AGN hosts broadly consistent with that observed in "inactive" galaxies (modest) enhancement observed only in low-mass samples

- COSMOS (high-Lx):
SFR in AGN hosts ~0.6 dex higher than in "inactive" galaxies, at all z/masses

(see also Silverman+2009, Xue+2010, Mullaney+2011)

see Lutz & Mullaney talks tomorrow!

Fact:
different enhancements at low and at high-L consistent with two different modes of SF and BH growth
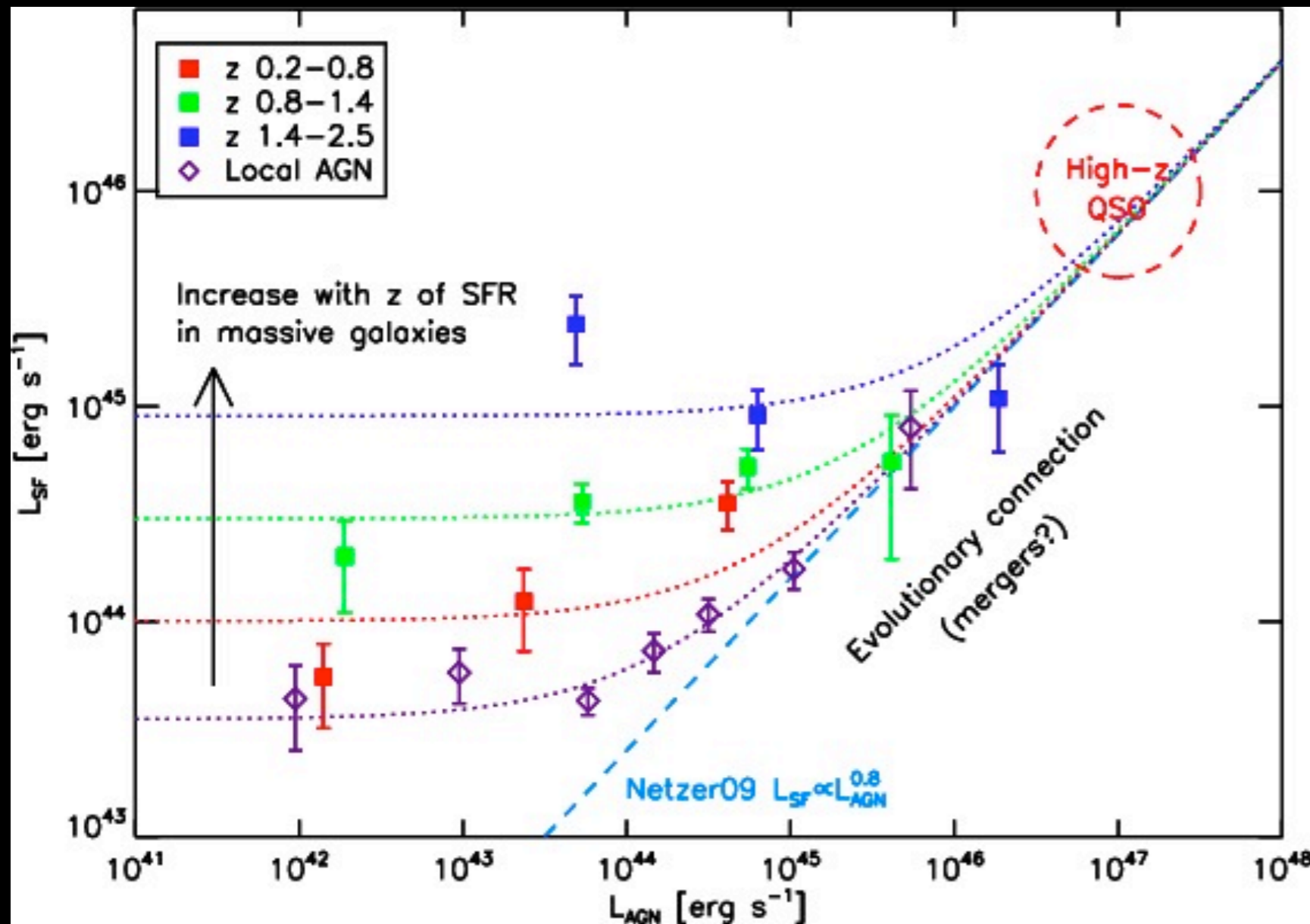
high-L: **major mergers**
low-L: **smooth accretion** (or mergers with delay in SB and AGN phases)

SF vs. AGN luminosity

Shao et al. 2010 [Herschel / GOODS-N X-ray AGN]
Rosario+in prep [Herschel / GOOS+COSMOS X-ray AGN]

at L(AGN)>45 (Lx>43.5)
correlation is observed, as
expected in mergers models

at L(AGN)<45 (Lx<43.5)
no correlation between AGN
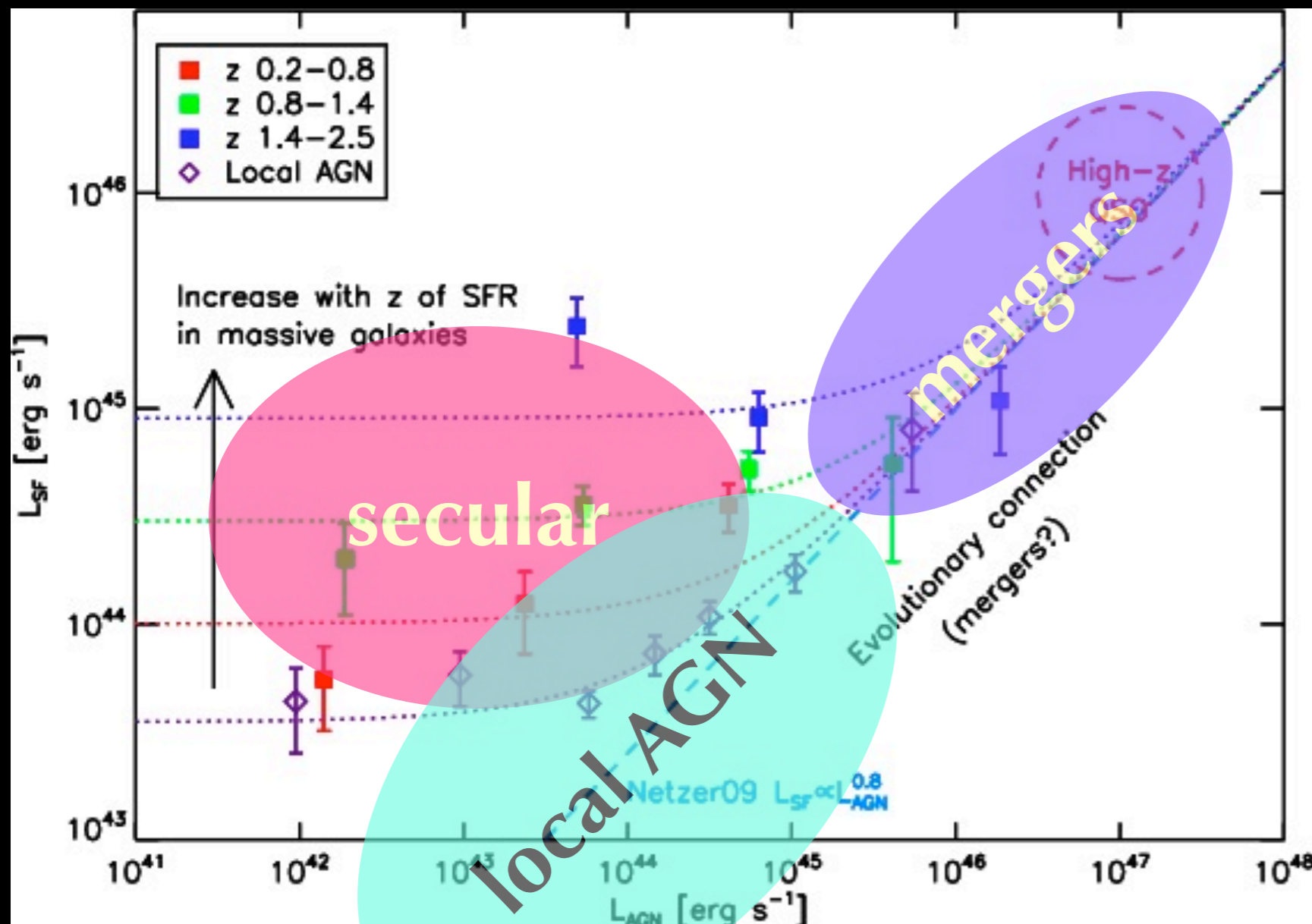and SF at z>0.2 and in local
X-ray selected samples

See Lutz and Mullaney talks!

see also Netzer+2007; Netzer2009; Lutz+2010

SF vs. AGN luminosity

Shao et al. 2010 [Herschel / GOODS-N X-ray AGN]
Rosario+in prep [Herschel / GOOS+COSMOS X-ray AGN]

at L(AGN)>45 (Lx>43.5)
correlation is observed, as expected in mergers models

at L(AGN)<45 (Lx<43.5)
no correlation between AGN and SF at z>0.2 and in local X-ray selected samples
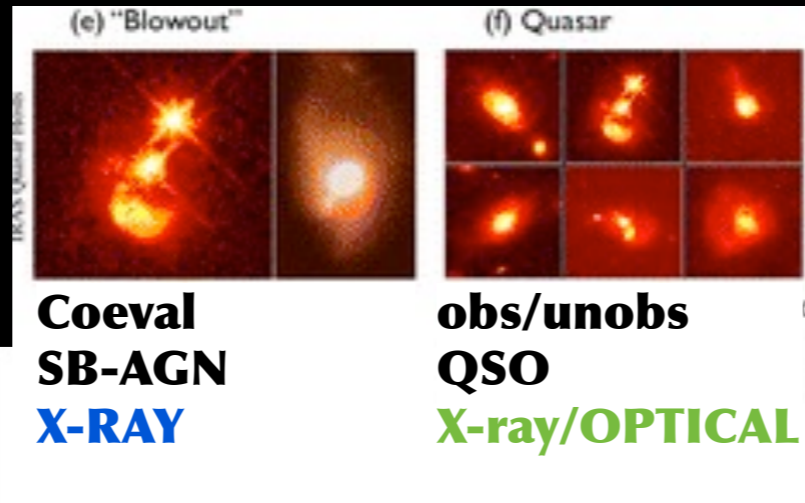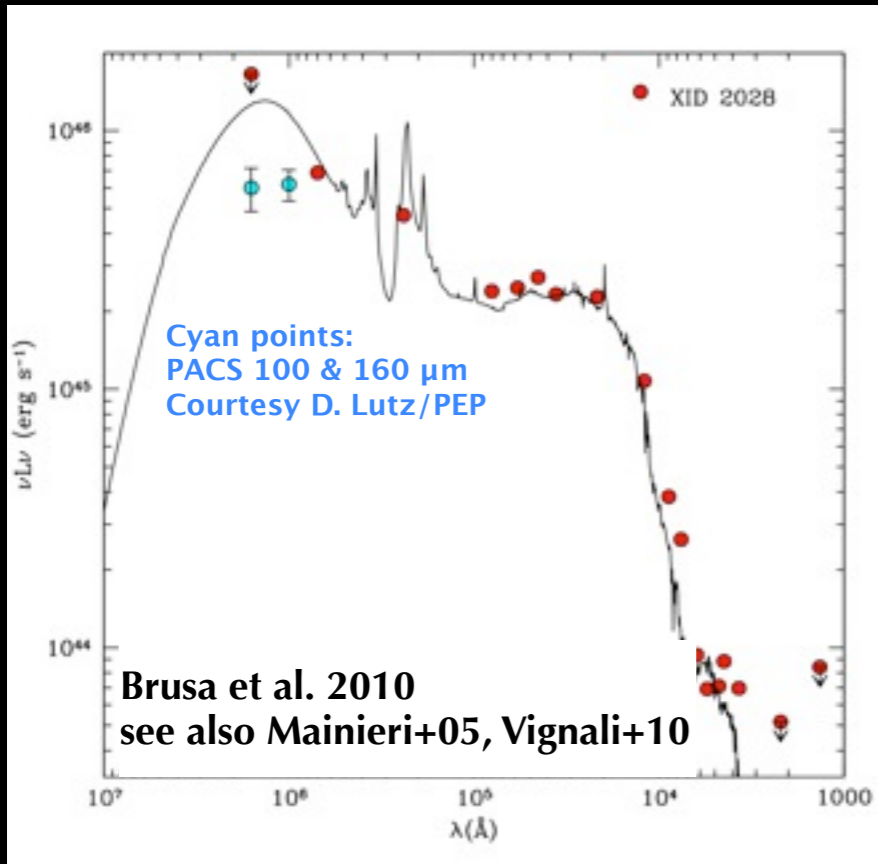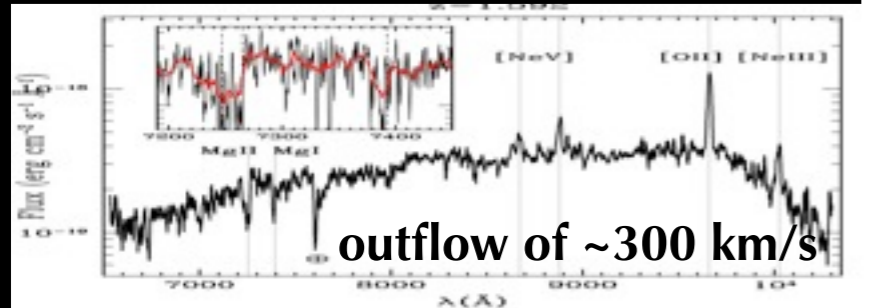
See Lutz and Mullaney talks!

see also Netzer+2007; Netzer2009; Lutz+2010

During or Post ?

Most **luminous**, **obscured X-ray selected** sources at z>1 are red
--> effect of (negative) feedback efficient in stopping star formation, or AGN is in dusty environment? Evidences for *both* !   --> **different phases/timescales are sampled**

evidence of SF both in FIR and optical spectra (see e.g. Del Moro, Mateos, Sani, Page, Symeonidis talks)
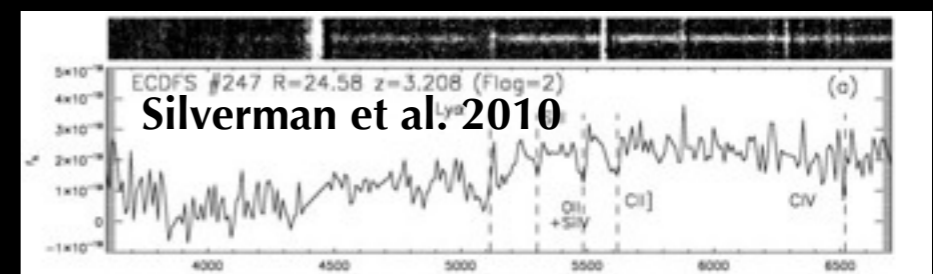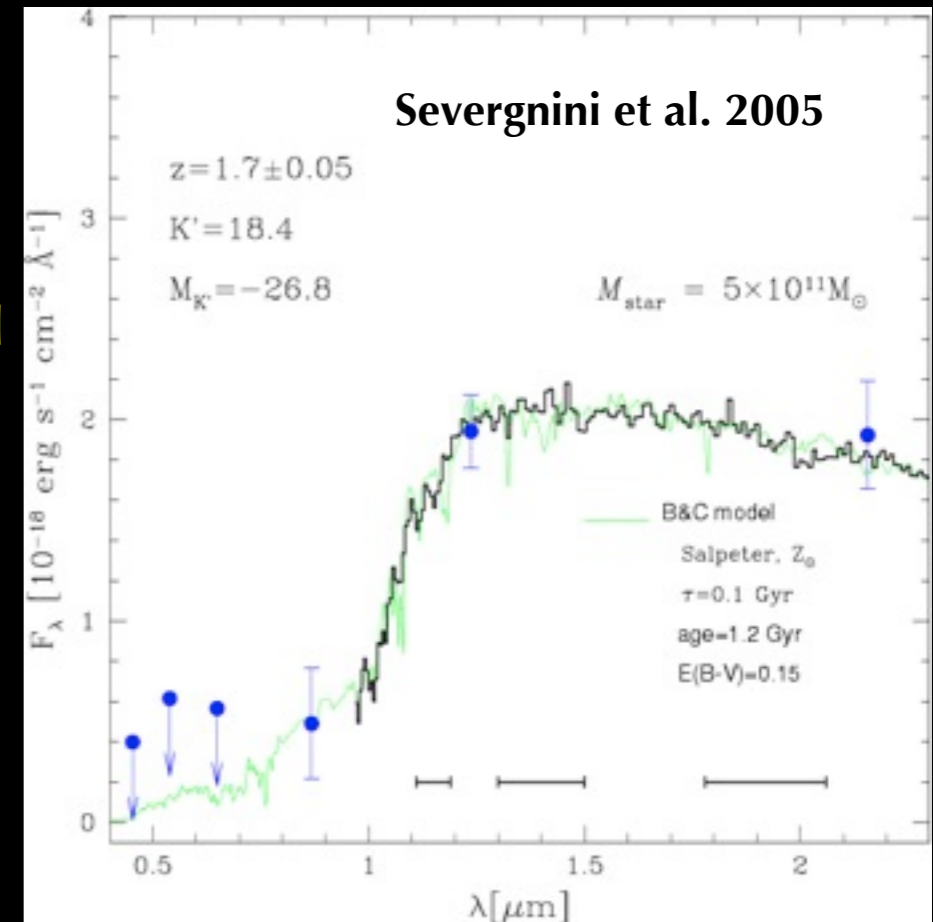
ULIRG-QSO2

outflow of ~300 km/s

Cyan points:
PACS 100 & 160 µm
Courtesy D. Lutz/PEP

XID 2028

Brusa et al. 2010
see also Mainieri+05, Vignali+10

(e) "Blowout"   (f) Quasar

Coeval SB-AGN
X-RAY

obs/unobs QSO
X-ray/OPTICAL

passive ellipticals/early type spectra without any sign of SF (see also Mignoli+2004, Brusa+2005, Daddi +2005....)

QSO2

Very short phase (<< 1Gyr): need large & bright samples (RARE OBJECTS!!)

Importance of X-ray selection, prospects for large area X-ray surveys (SWIRE/XMM-XXL/ eROSITA)

Ideal targets for WFC3/ X shooter/ ALMA/JWST follow-up and deep spectroscopy

Severgnini et al. 2005

z=1.7±0.05
K'=18.4
$M_{K'} = -26.8$
$M_{star} = 5 \times 10^{11} M_\odot$

B&C model
Salpeter, $Z_\odot$
τ=0.1 Gyr
age=1.2 Gyr
E(B-V)=0.15

Silverman et al. 2010

AGN hosts morphologies

Cisternas et al. (2010) - z~1 AGN hosts morphologies in COSMOS (HST/ACS)
Kocevski et al. (2011) - z~2 AGN hosts morphologies in CDFS (HST/WFC3)
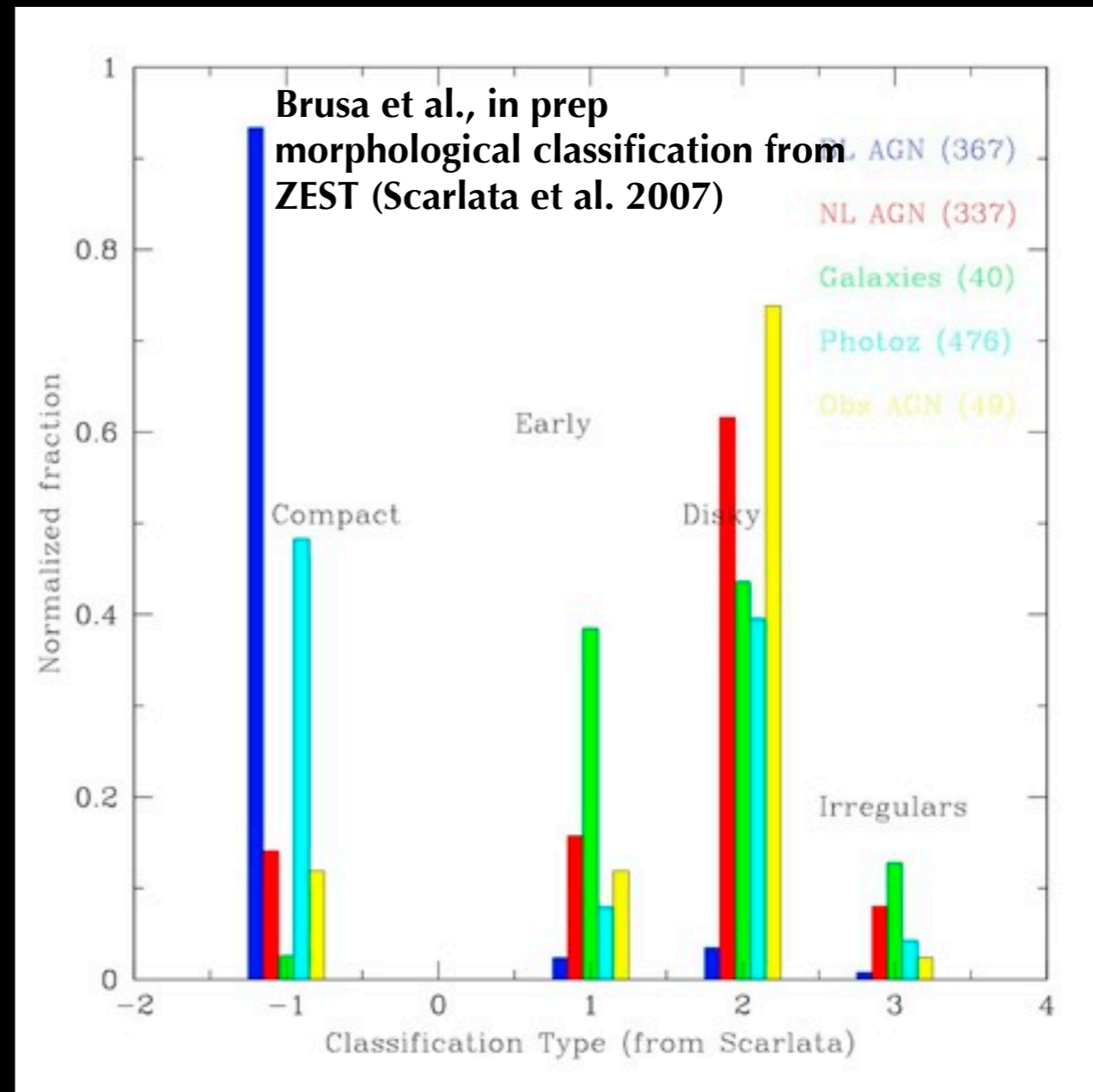
Morphologies of AGN hosts

Sanders+1988 (QSO): local QSO/ULIRGs hosted in **highly disturbed systems, evidence for mergers**

Cisternas+10 (AGN at z<1): >85% of AGN host galaxies **do not show strong distortions**; **no enhancement in mergers fraction** among AGN morphologies wrt normal galaxy population (see also Grogin+03, Pierce+07, Georgakakis+09, Gabor+2009)
--> **no major merger AGN connection**

Kocevski+11, Schawinski+2011 (AGN at z=1-3):
NO significant excess of distorted morphologies; large fraction reside in **late-type galaxies**, fueled by stochastic accretion of cold-gas

Lx dependence: low-L = mostly disks
                high-L = mostly ellipticals/relaxed
                          systems
               (but see results from Manieri+2011)

Brusa et al., in prep
morphological classification from
ZEST (Scarlata et al. 2007)

Fact:
high disk fraction (and no distortion) at odds with predictions that merger driven accretion is the dominant AGN fueling mode

Combining results from SFR & morphologies

1) SF in AGN hosts is only slightly enhanced (ULIRG in only a small fraction of hosts, even at the highest L) and morphologies of AGN do not show strong distortions

2) Luminosity effect is observed (both in SFR enhancement and morphologies)

Time delay between AGN activity, SF and merger?
(predicted in simulations involving AGN feedback, e.g. Hopkins+2006, Wild+2010)
--> can explain the SFR enhancement observed in low-Lx/low-mass systems but not the disky morphologies ...

Secular evolution / smooth accretion fit better both observed morphologies and SFR
--> major mergers model crisis also for moderate/high-L (Di Matteo et al. 2011, Bournaud et al. 2011)

Merger path NOT the rule (timescale problem)... or...
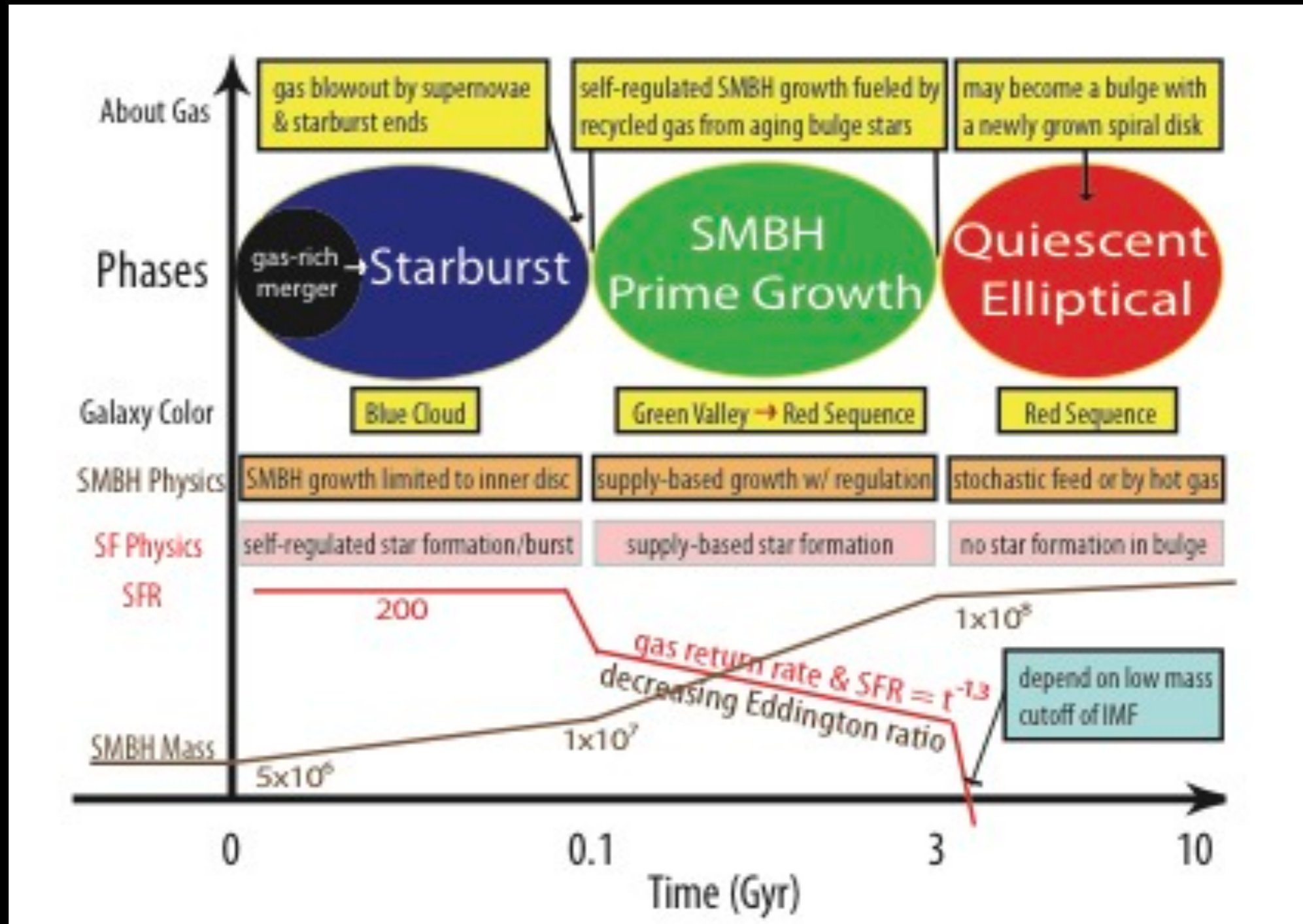
"Cen Scenario": NO AGN feedback

Cen 2011

NO causal relation

SF and BH growth are self regulated and independent

Starformation starts through mergers or secular processes (not important)

(timescales involved are much longer with respect to Hopkins et al. 2008!)

Summary

Summary

Evidence of Starburst-AGN connection:

local scaling relations and SF/AGN downsizing

Dichotomy in formation history of galaxies

mergers vs. secular

Fact:

obscured AGN are RED, but not particularly redder or luminous than inactive galaxies of same mass

Fact:

Obscured AGN associated to SF galaxies **do not scatter significantly off the main sequence of SF galaxies)**

Fact:

high disk fraction (and no distortion) at odds with predictions that merger driven accretion is the dominant AGN fueling mode

Fact:

different enhancements at low and at high-L consistent with two different modes of SF and BH growth

Fact:

50% X-ray selected obscured AGN are actively forming stars (>20 Msun/year or 1/SSFR<t_Hubble) at almost all redshifts

....or no causal relation at all (no AGN feedback)

Importance of combined X-ray/FIR coverage to isolate obscured accreting black holes at high-z and study host galaxies properties

Essential role of Herschel in disentangling starburst component ..... essential role of XMM/Chandra in revealing AGN !

(multiwavelength limelight)

Thanks !

(Results obtained in the framework of the COSMOS & CDFS/MUSIC/PEP teams)