ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Co-evolution of supermassive black holes and galaxies within their large-scale structures

John Silverman (ETH-Zurich)

ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Collaborators

zCOSMOS

ETH: S. Lilly
M. Carollo
K. Caputi
P. Kampczyk
C. Knobel
K. Kovac
C. Maier
Y. Peng

LAM/LATT: O. Le Fevre
J.-P. Kneib
L. De Ravel
V. Le Brun
L. Tasca
L. Tresse
T. Contini
S. De La Torre
F. Lamareille

INAF: G. Zamorani
M. Bolzonella
O. Cucciati
B. Garilli
A. Iovino
M. Mignoli
M. Scodeggio
D. Vergani
E. Zucca

MPE/ESO: V. Mainieri
A. Bongiorno
M. Tanaka

& full zCOSMOS team

xCOSMOS

G. Hasinger (MP-IPP)
M. Elvis (CfA)
H. Brunner (MPE)
M. Brusa (MPE)
N. Cappelluti (MPE)
F. Civano (CfA)
A. Comastri (INAF-Bologna)
A. Finoguenov (MPE)
F. Fiore (INAF-Rome)
R. Gilli (INAF-Bologna)
R. Griffiths (CMU)
A. Koekomoer (STSCI)
T. Miyaji (IAUNAM)
C. Vignali (Univ. Bologna)
M. Salvato (CalTech)

COSMOS

D. Sanders (IfA)
N. Scoville (CalTech)
P. Capak (SSC)
K. Jahnke (MPIA)
J. Kartaltepe (IfA)
A. Merloni (MPE)
& full team

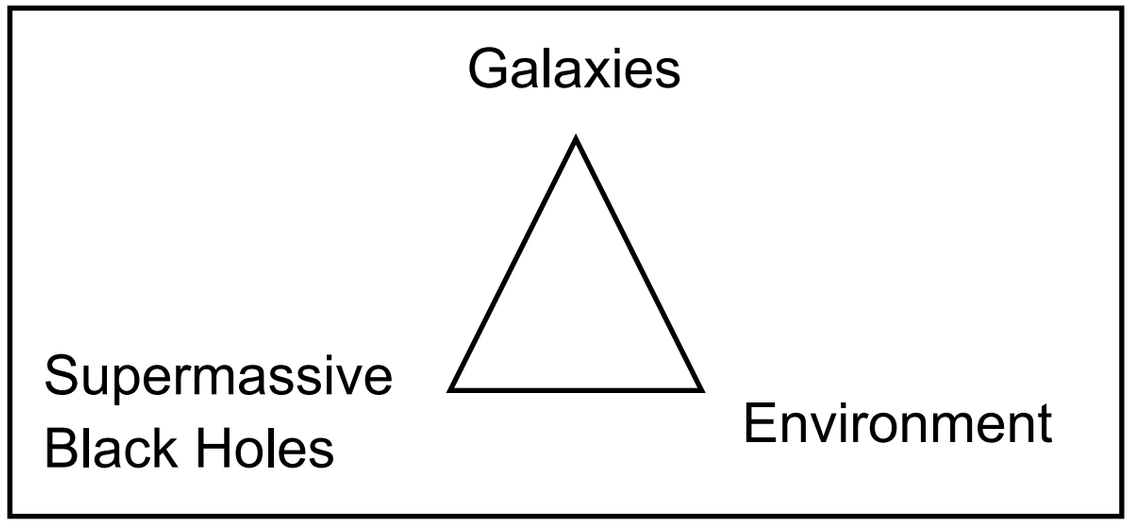
Chandra Deep Field South

W. N. Brandt (PSU)
D. Alexander (Durham)
F. Bauer (Univ. Columbia)
J. Bergeron (IAP)
B. Lehmer (Durham)
B. Luo (PSU)
P. Rosati (ESO)
D. Schneider (PSU)
G. Szokoly (EU-Hungary)
P. Tozzi (INAF-Trieste)
L. Wisotski (AIP)

ChaMP

P. Green (CXC)
B. Wilkes (CXC)
W. Barkhouse (UI)
D.-W. Kim (CfA)
M. Kim (SNU)
H. Tananbaum (CXC)

What are the fundamental questions?



Do supermassive black holes (SMBHs) play a role in galaxy evolution?

I. $z < 0.3$
- Local SMBH - bulge mass relations
- AGN activity/star formation connection (Sloan Digital Sky Survey)

II. Up to z~1
- AGN/star formation connection over the last 8 billion years
- Galaxy redshift surveys: *Chandra* Deep Field - South, (z)COSMOS
- AGN identification through X-ray emission (*Chandra*, XMM-Newton)

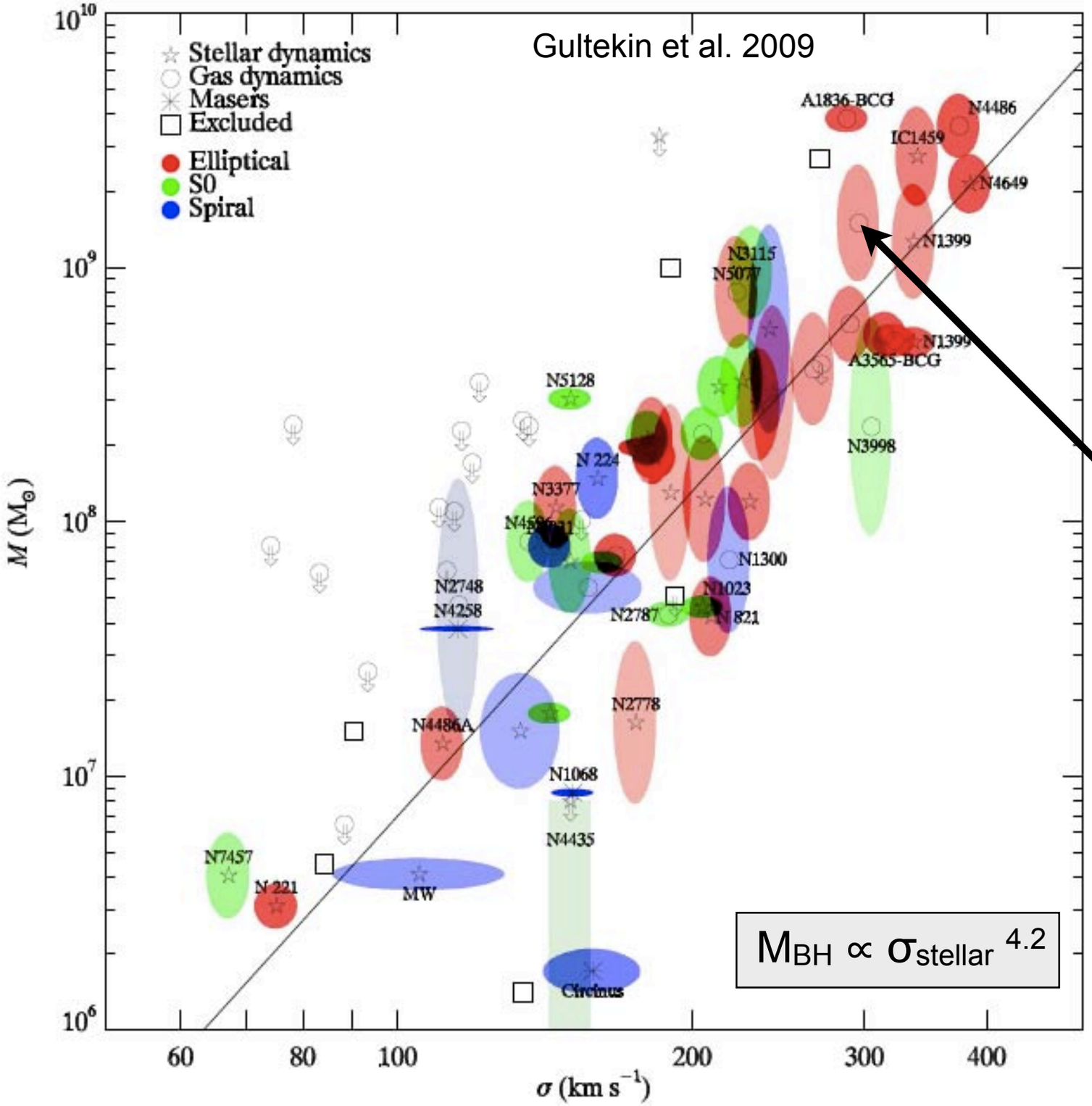
How is AGN and star formation influenced by their large-scale environments?

- Occurrence of AGN activity as a function of local galaxy density (zCOSMOS)

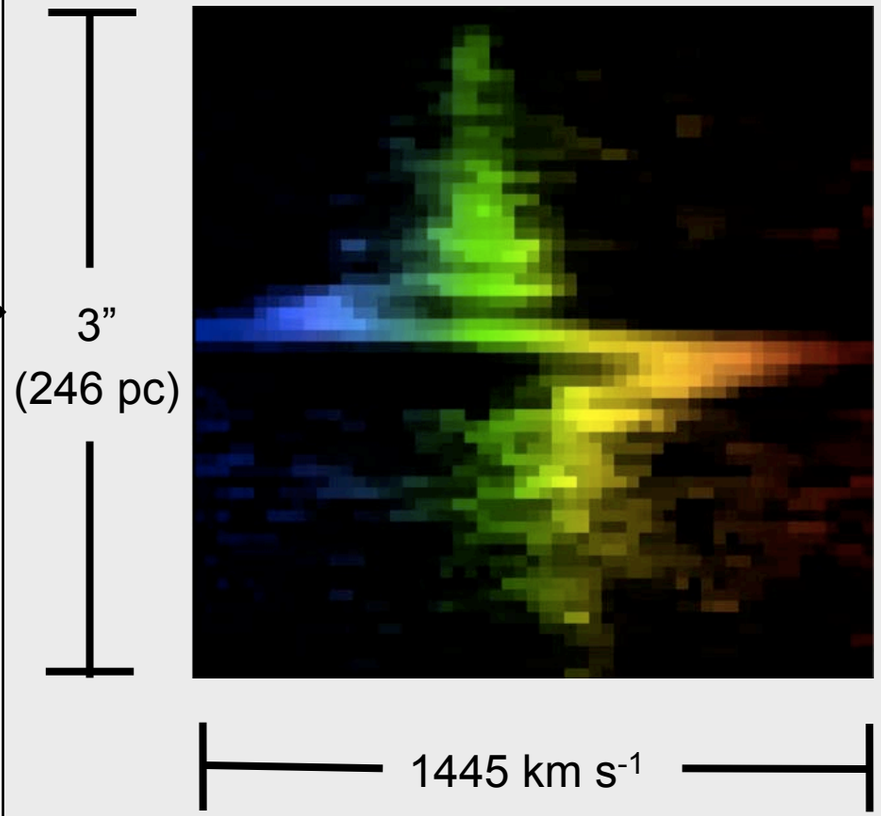
What physical mechanism(s) is driving accretion onto SMBHs?

Local SMBH-bulge relation

Gultekin et al. 2009



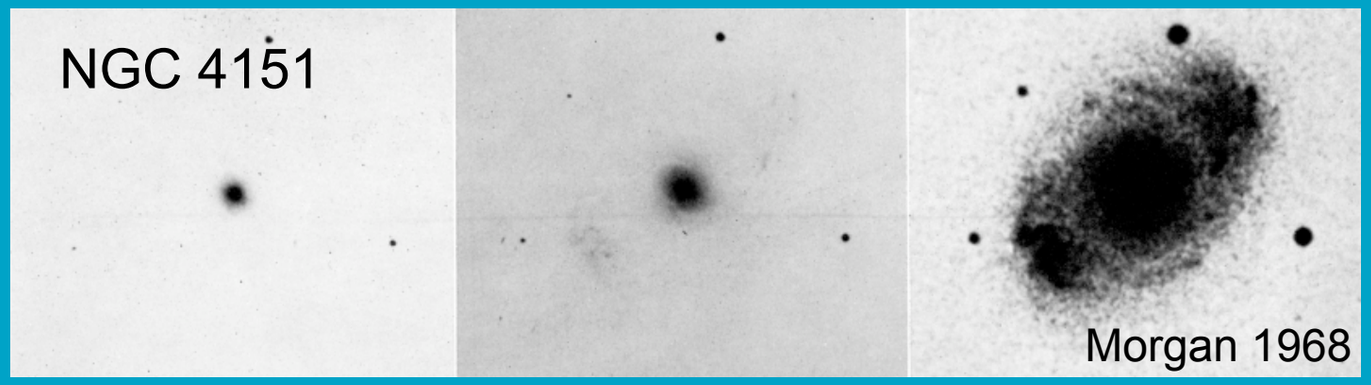
Gas kinematics:
nuclear region of M84
(HST/STIS)

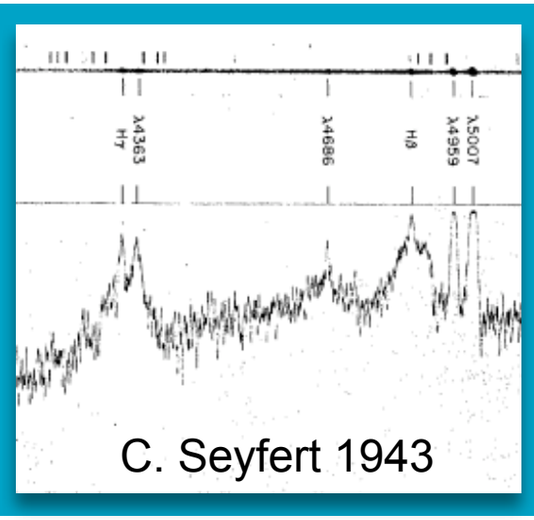


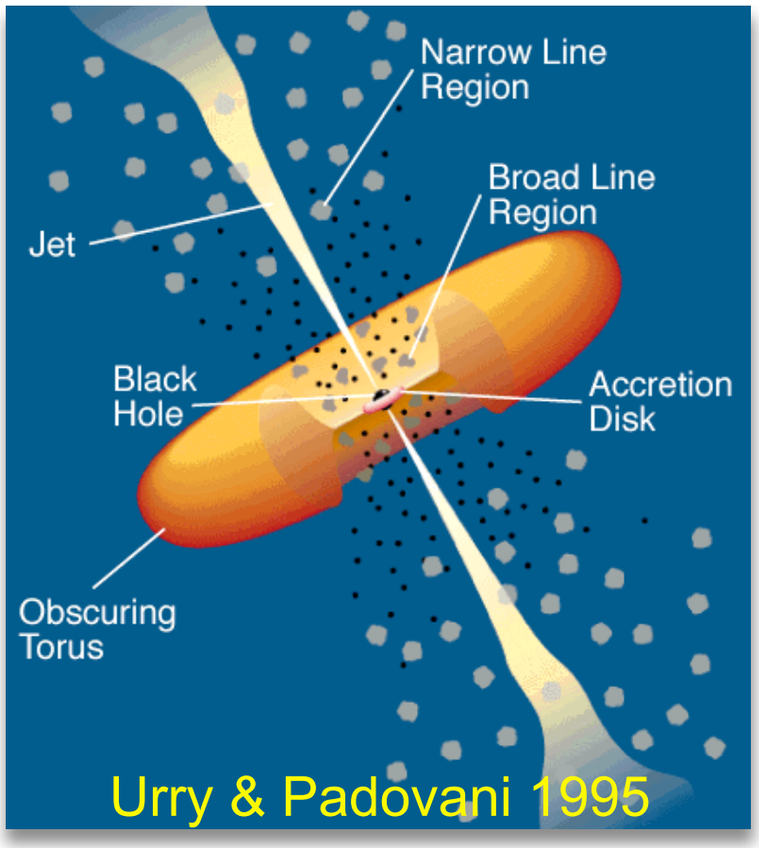
Bower et al. 1998

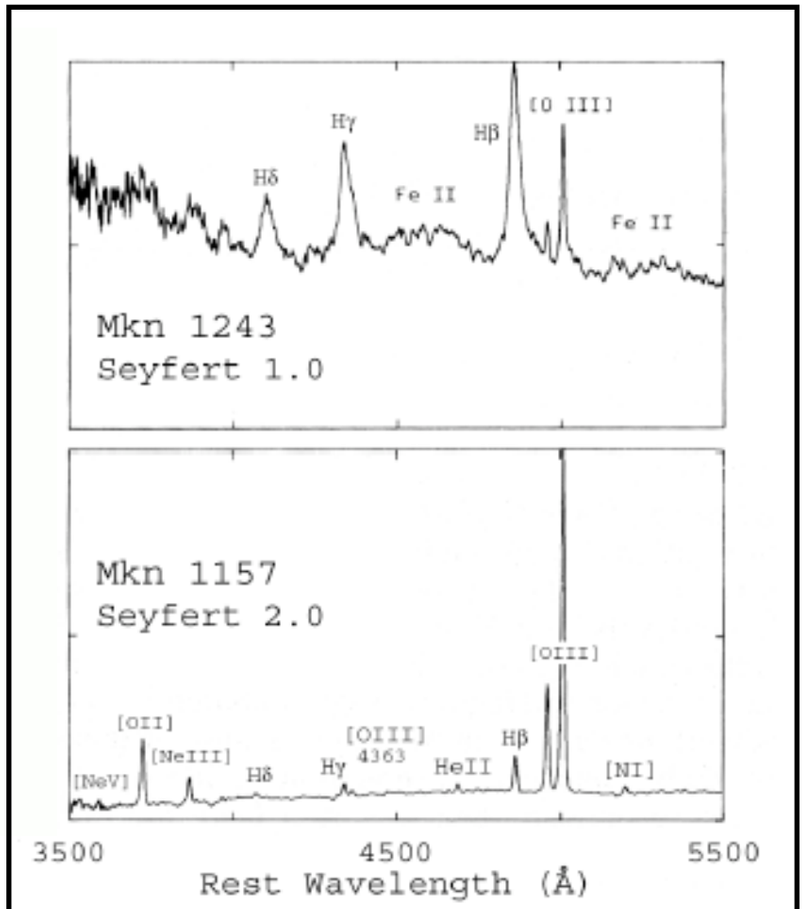
Gebhardt et al. 2000; Ferrarese & Merritt 2000; Tremaine et al. 2002

Accreting SMBHs: AGNs and QSOs

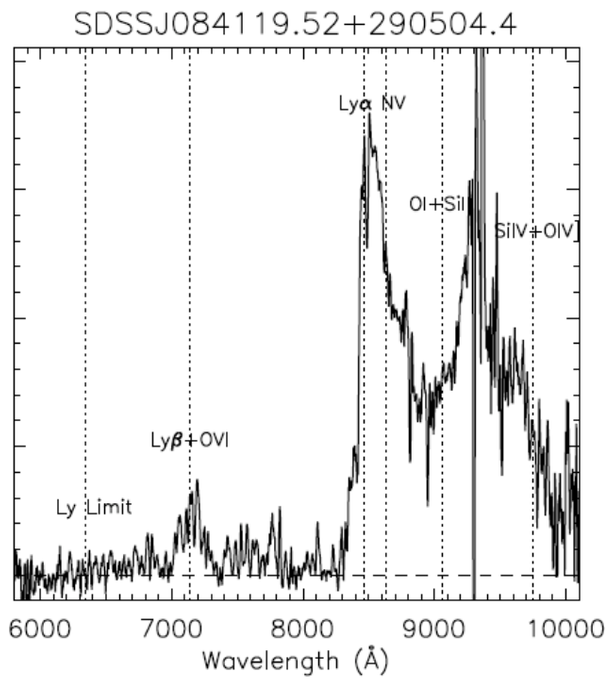








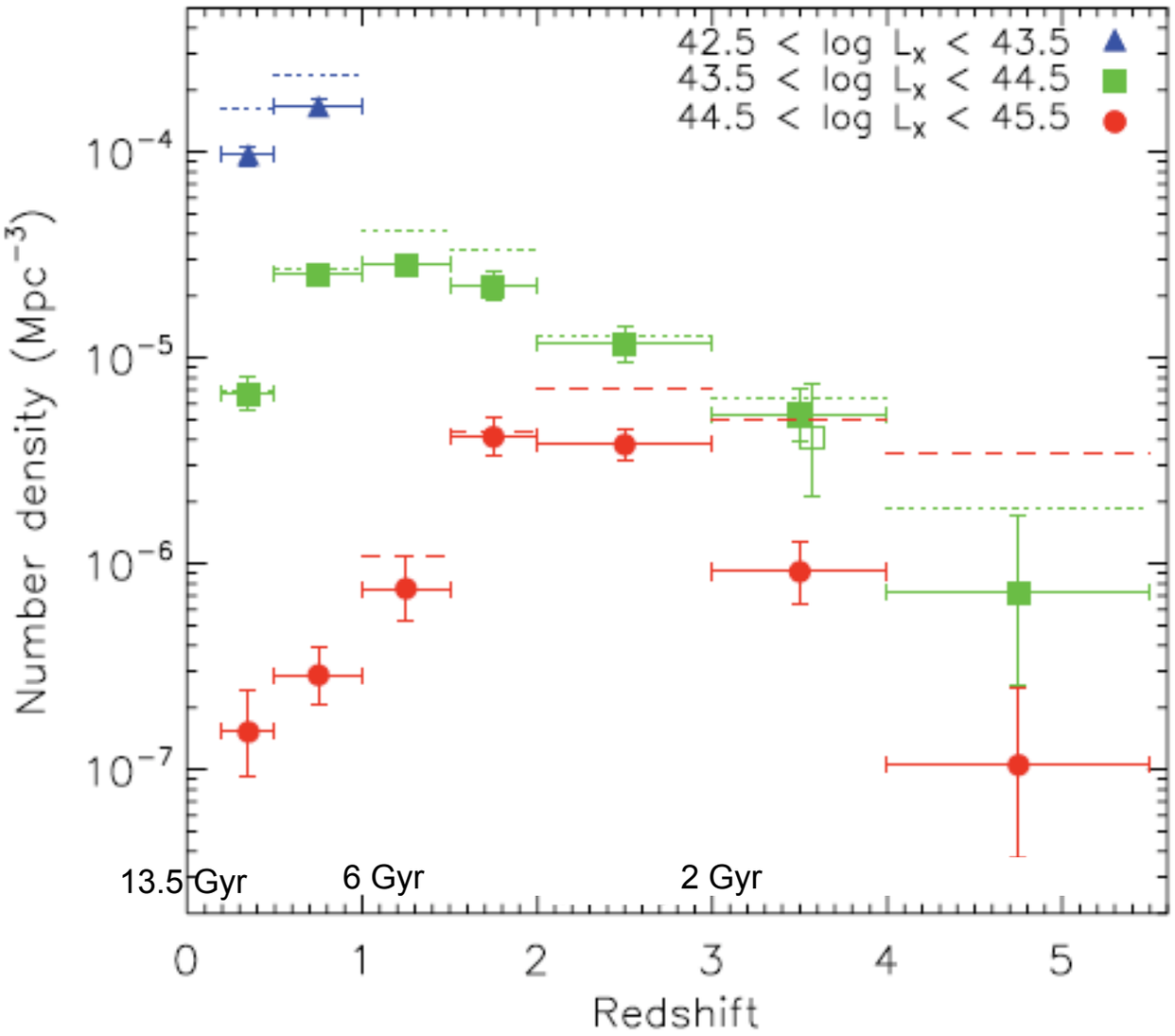
Whittle 2001 (adapted from Osterbrock 1984)

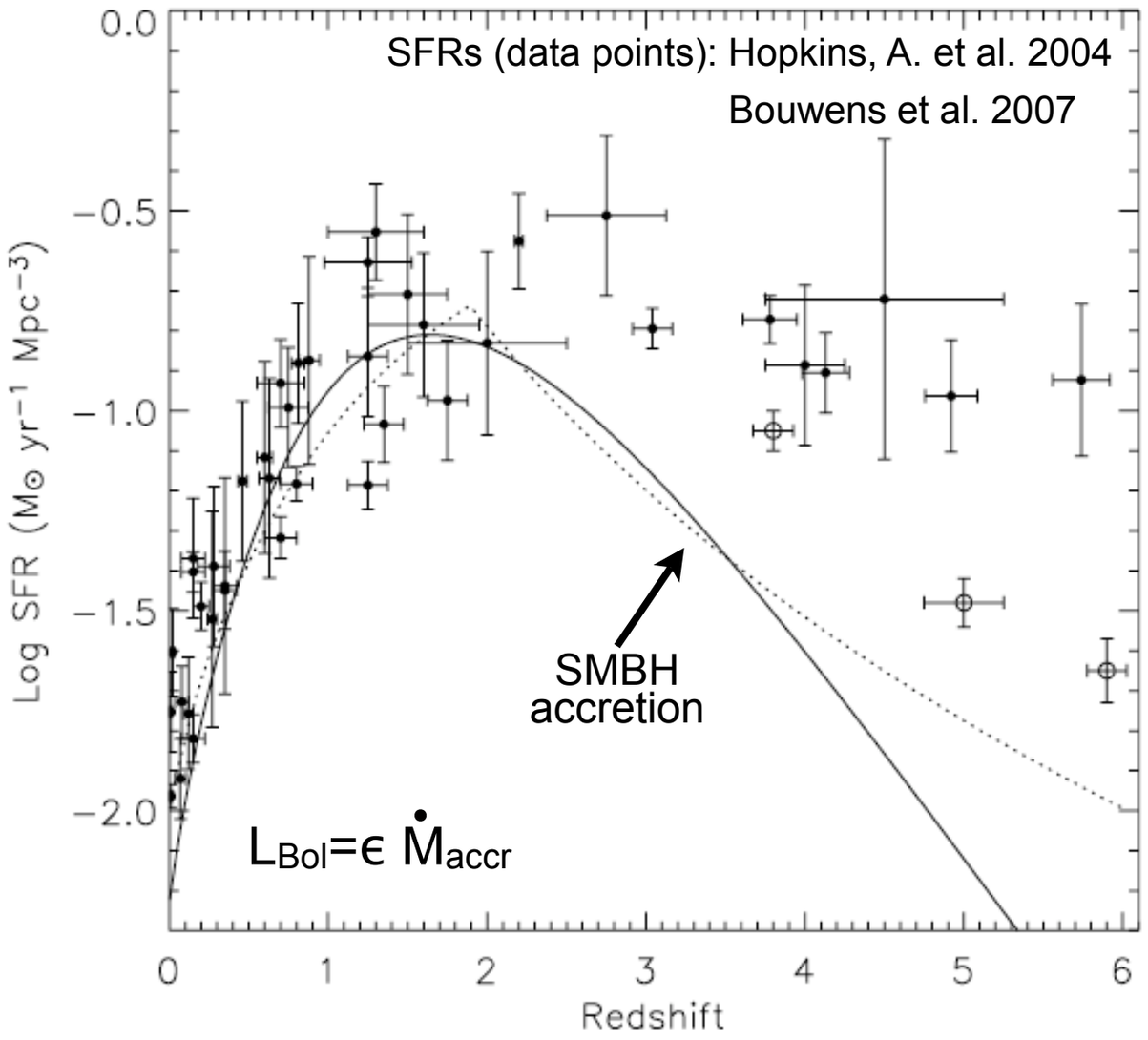


QSO (z=5.96)
Subaru/FOCAS
Goto (2006)

Cosmological evolution of SMBHs

Comoving space density of X-ray selected AGN





Silverman et al. 2008b, ApJ, 679, 118

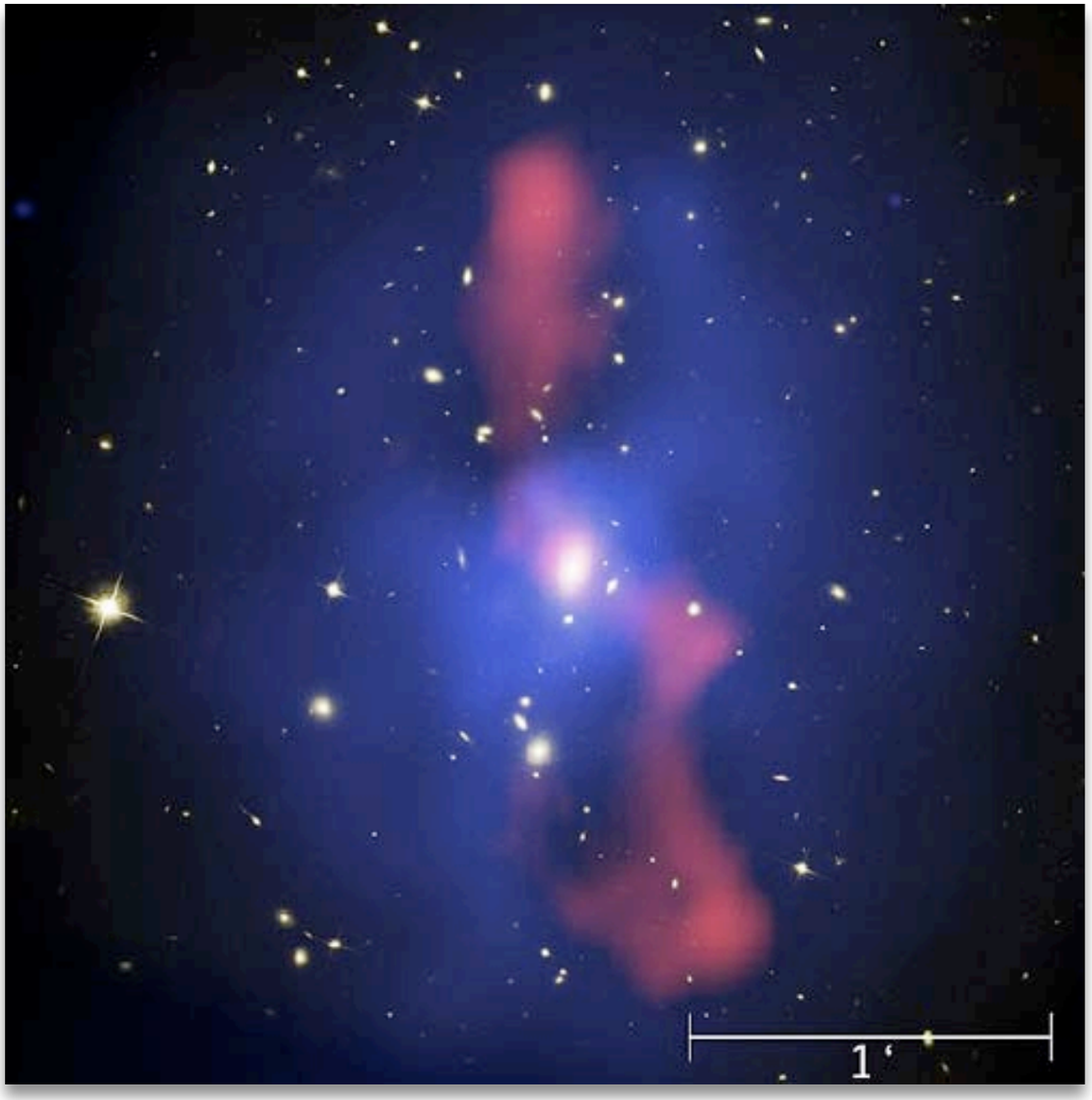
See also Boyle & Terlevich 1998; Franceschini, Hasinger & Miyaji 1999; Merloni, Rudnick, Di Matteo 2004; Marconi et al. 2004; Shankar et al. 2008

Fueling mechanisms of AGN

What physical process drives the concurrent growth of SMBHs and their host galaxies?

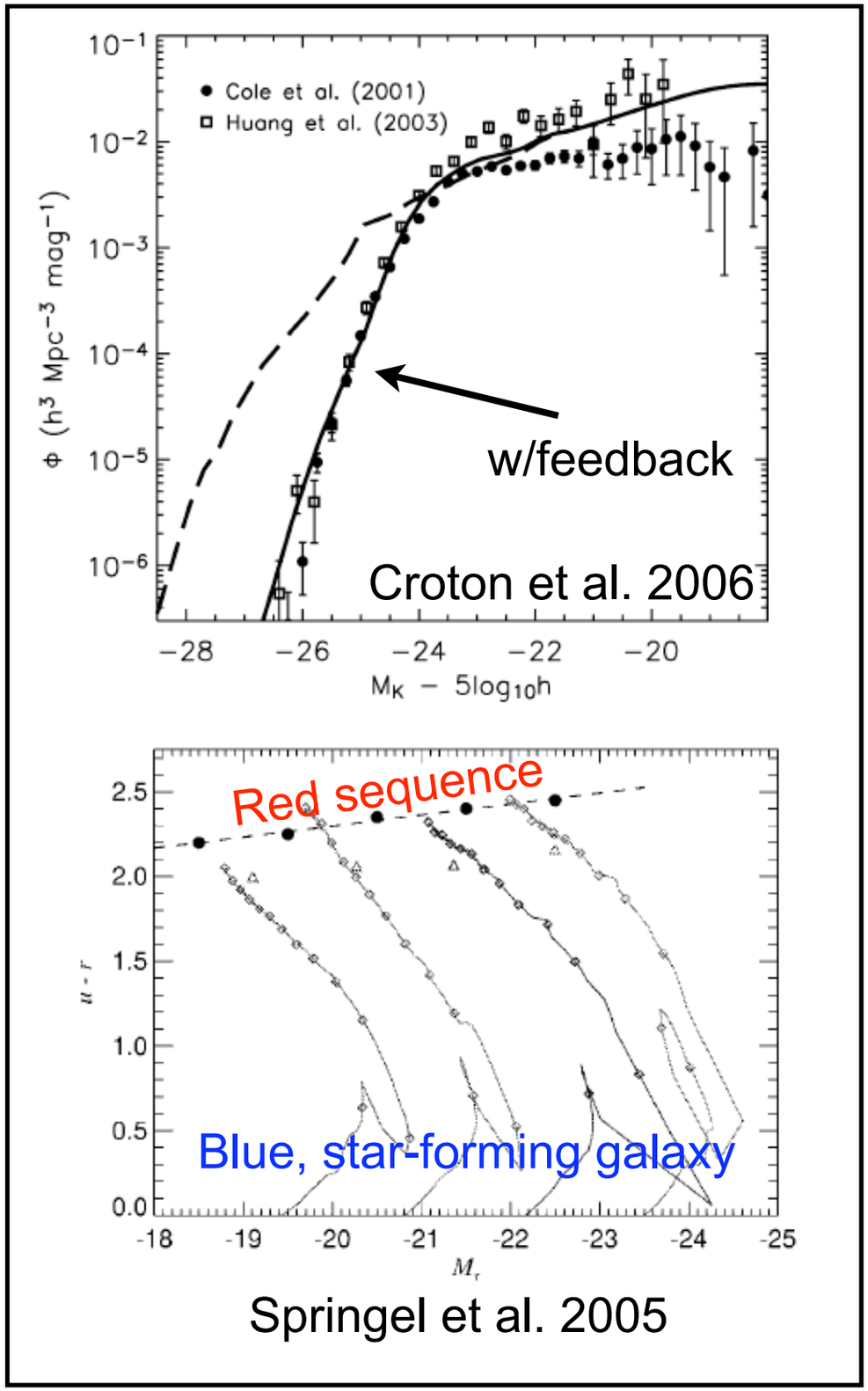
- **Major mergers of galaxies**
  - ✦ *Ultraluminous infrared galaxies:*
    - High central gas concentrations and AGN activity (see Sanders & Mirabel 1996; Iwasawa et al. 2005).
  - ✦ *Numerical simulations* demonstrate that mergers:
    - Effectively able to form ‘classical’ bulges from spiral/disk galaxies (e.g., Hernquist 1993)
    - Transfer gas to the nucleus (Mihos & Hernquist 1996) thus powering AGN (e.g. Hopkins et al. 2008)
    - Self-regulating AGN feedback and quenched star formation (Di Matteo et al. 2005, Springel et al. 2005, Croton et al. 2006)
  - ✦ *Observed merger rate increases with redshift* (e.g., Kartaltepe et al. 2007; de Ravel et al. 2008)
- **Internal processes**
  - ✦ Bar/disk instabilities (Kormendy & Kennicutt 2004)
  - ✦ Stellar ejecta (e.g., Davies et al. 2007; Kauffmann et al. 2009)
- ✴ **Availability of gas**
  - ✦ Plentiful reservoir of molecular gas on large (kpc) scales (Scoville et al. 2003; Ho et al. 2008)

AGN feedback



X-ray Radio

McNamara et al. 2008



Springel et al. 2005

Merger-induced accretion

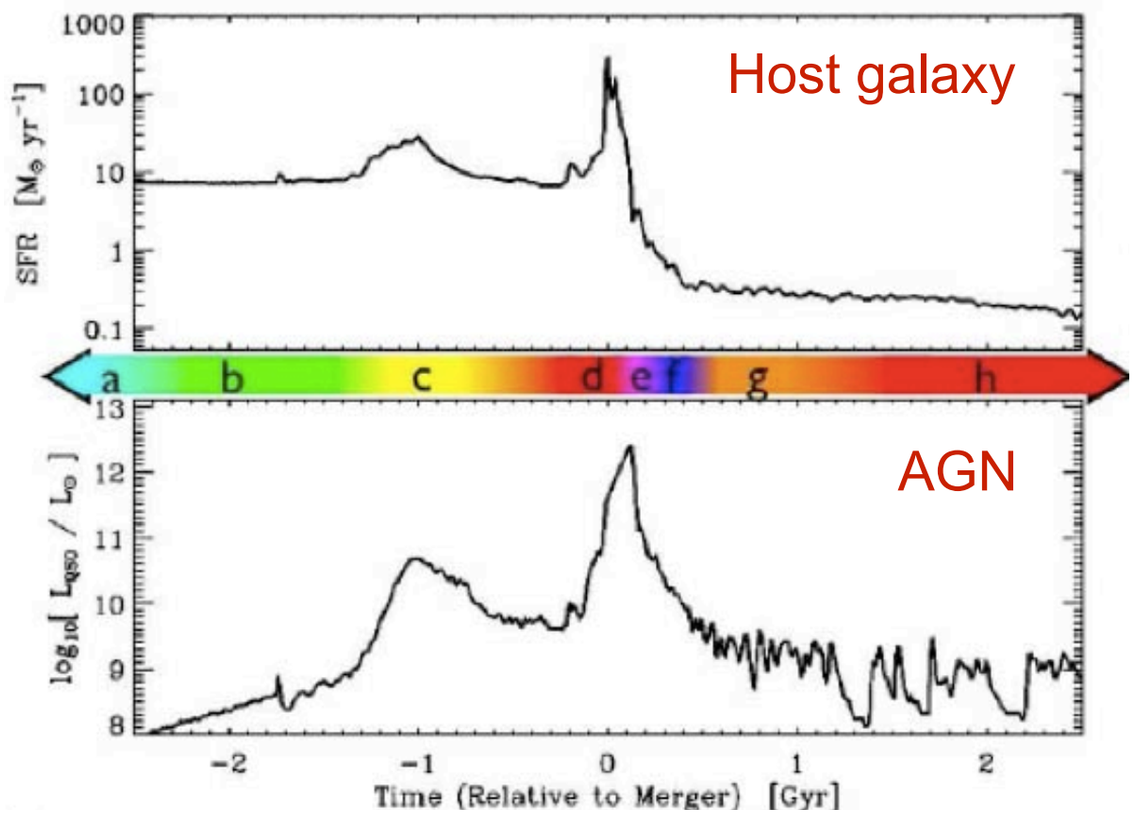
Evolutionary sequence

Merger ⟶ ULIRG ⟶ QSO

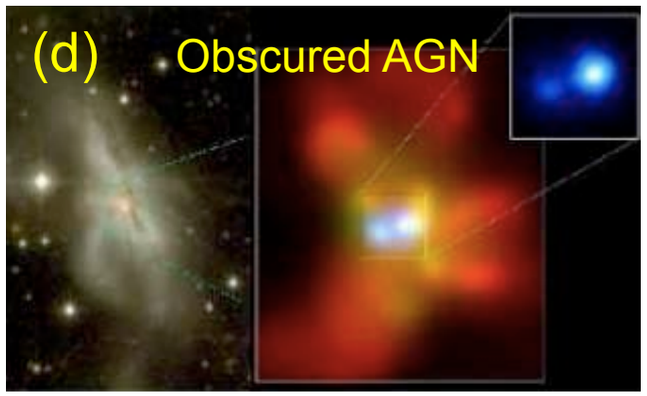
Sanders et al. 1988

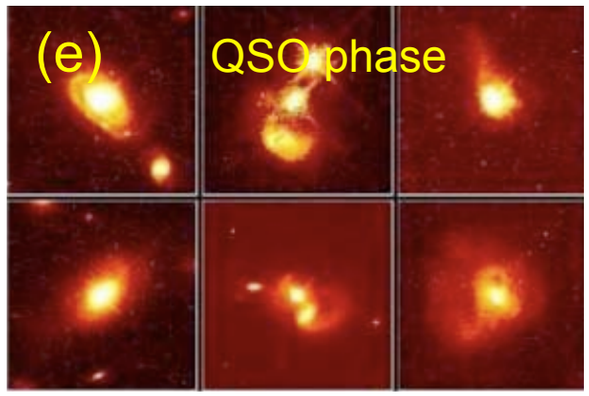
➡ Similar bolometric luminosities ($L \sim 10^{12}\ L_\odot$)

➡ space densities ($\Phi \sim 10^{-5}\ \mathrm{Mpc}^{-3}$)



Hopkins et al. 2008



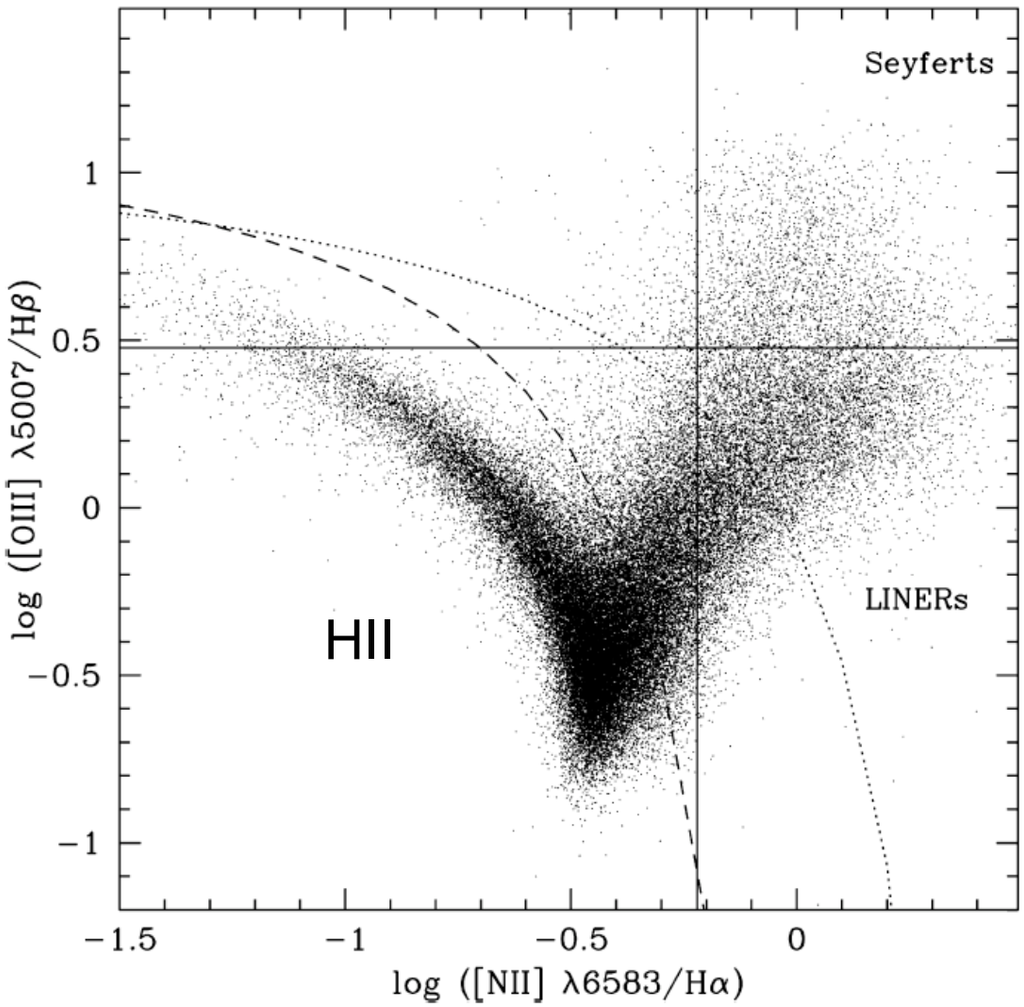


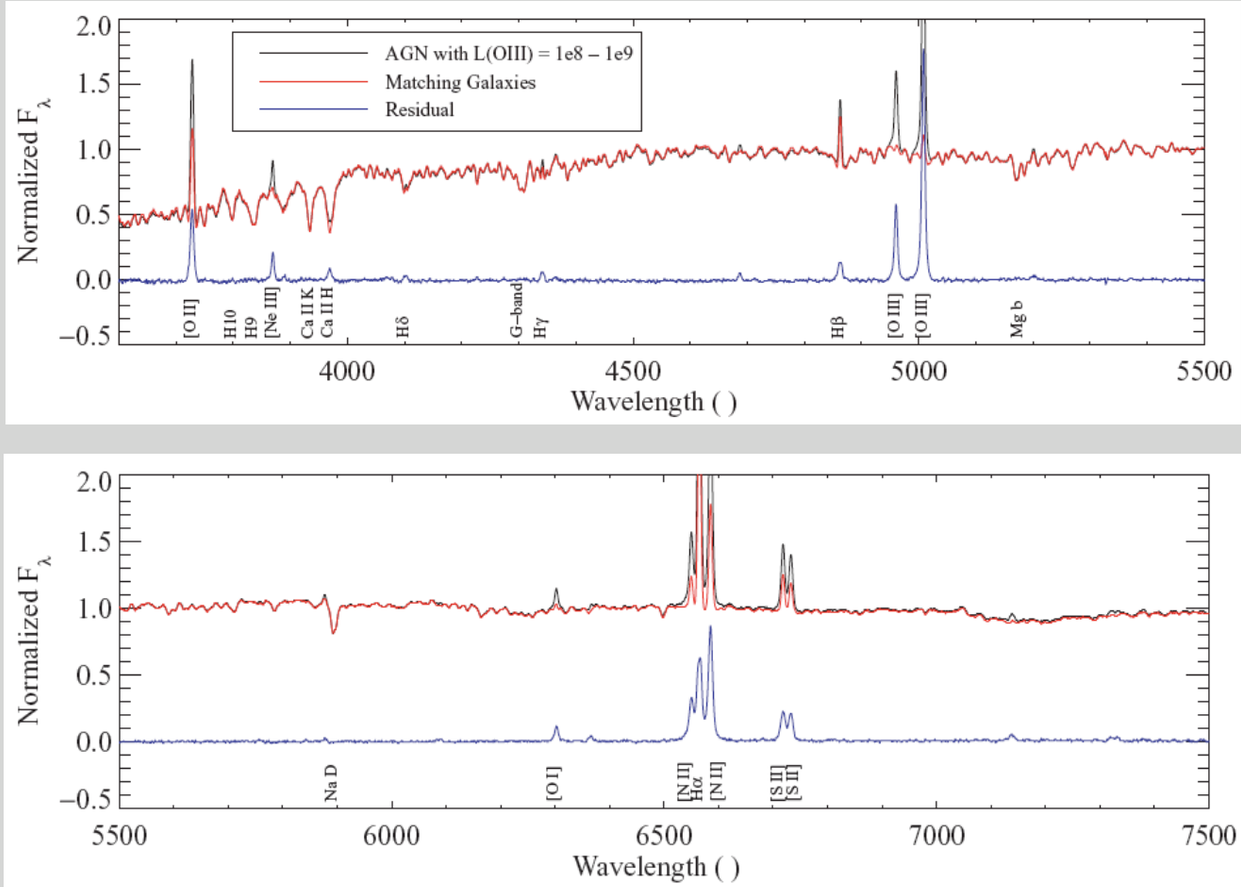
Is there an AGN/star formation connection?

AGN/SF connection at z < 0.3 (SDSS)

Type 2 AGNs: Nature's 'cosmic coronograph'

Selection based on emission-line ratios

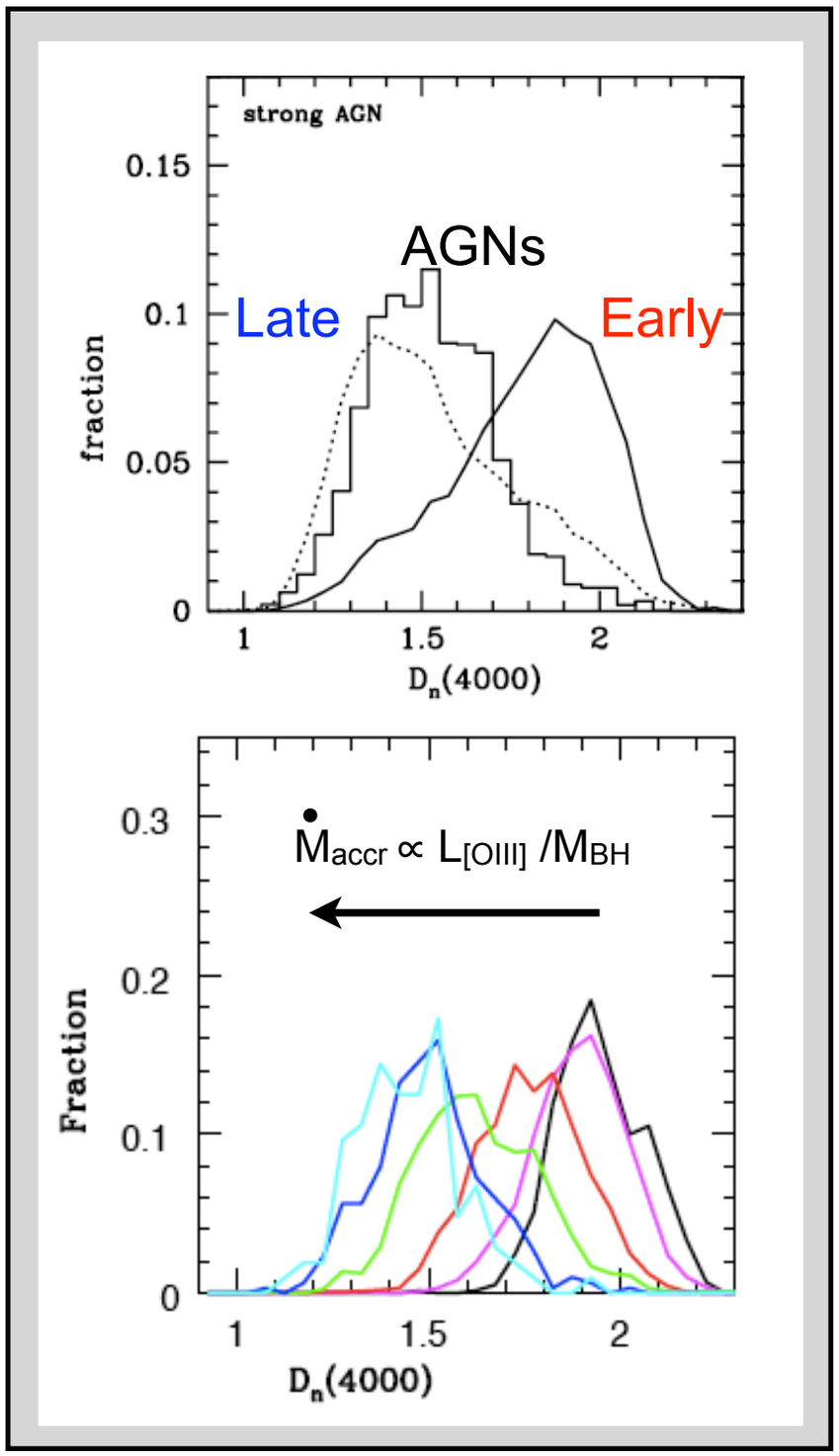


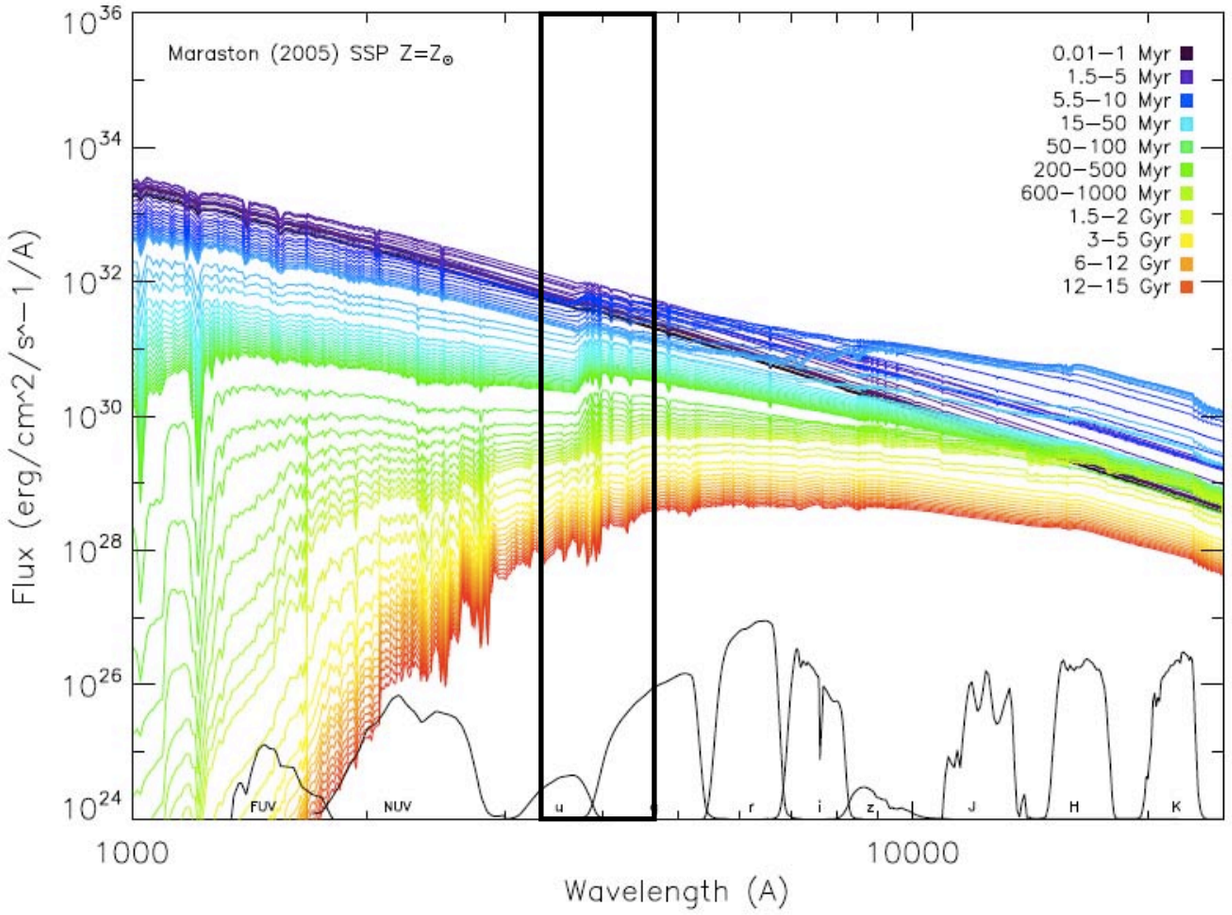


Kauffmann et al. 2003

See also Veilleux & Osterbrock 1987; Kewley et al. 2001, 2006; Stasinska et al. 2007

AGN/SF connection at z < 0.3 (SDSS)



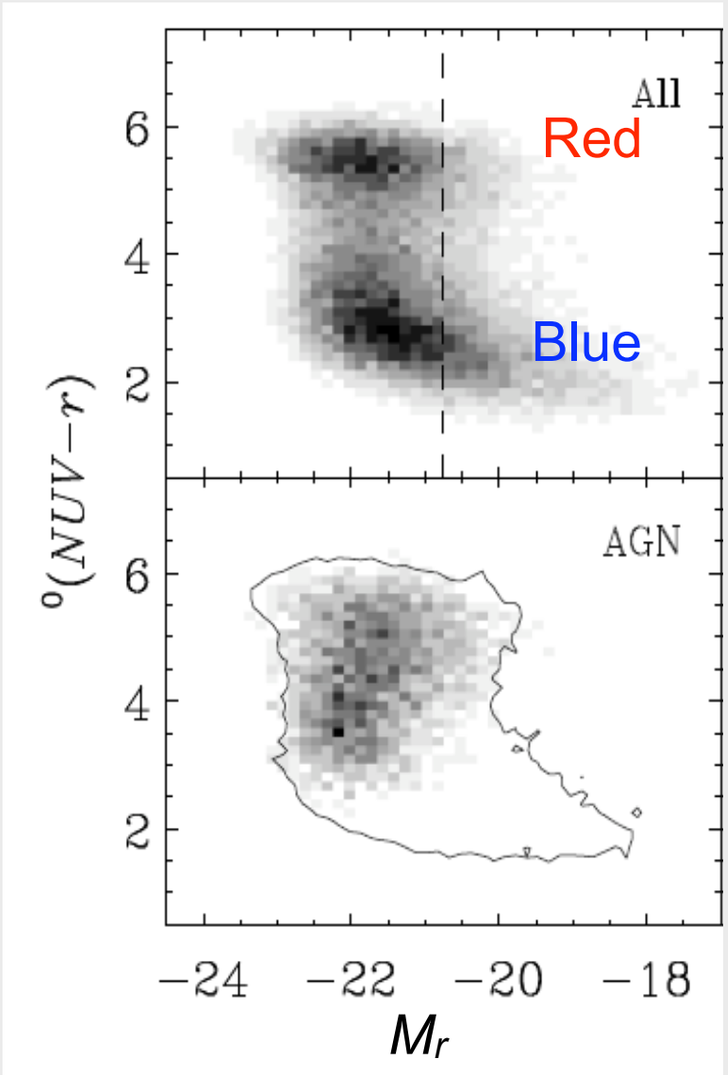


Schawinski et al. 2007

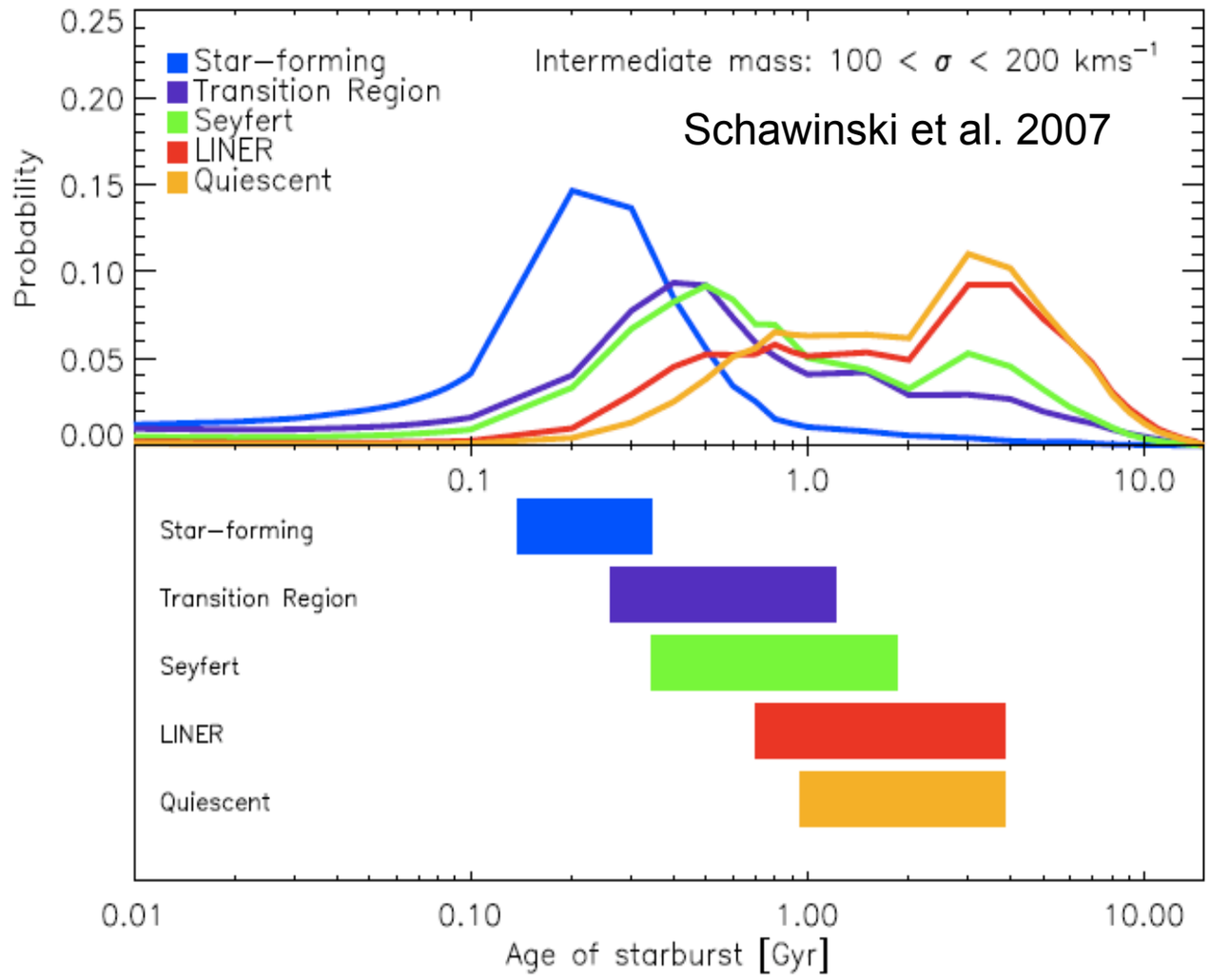
Young stellar populations are associated with strongly accreting SMBHs

Kauffmann et al. 2003, 2007

AGN/SF connection at z < 0.3 (SDSS)



Salim et al. 2007
(See Martin et al. 2007 as well)

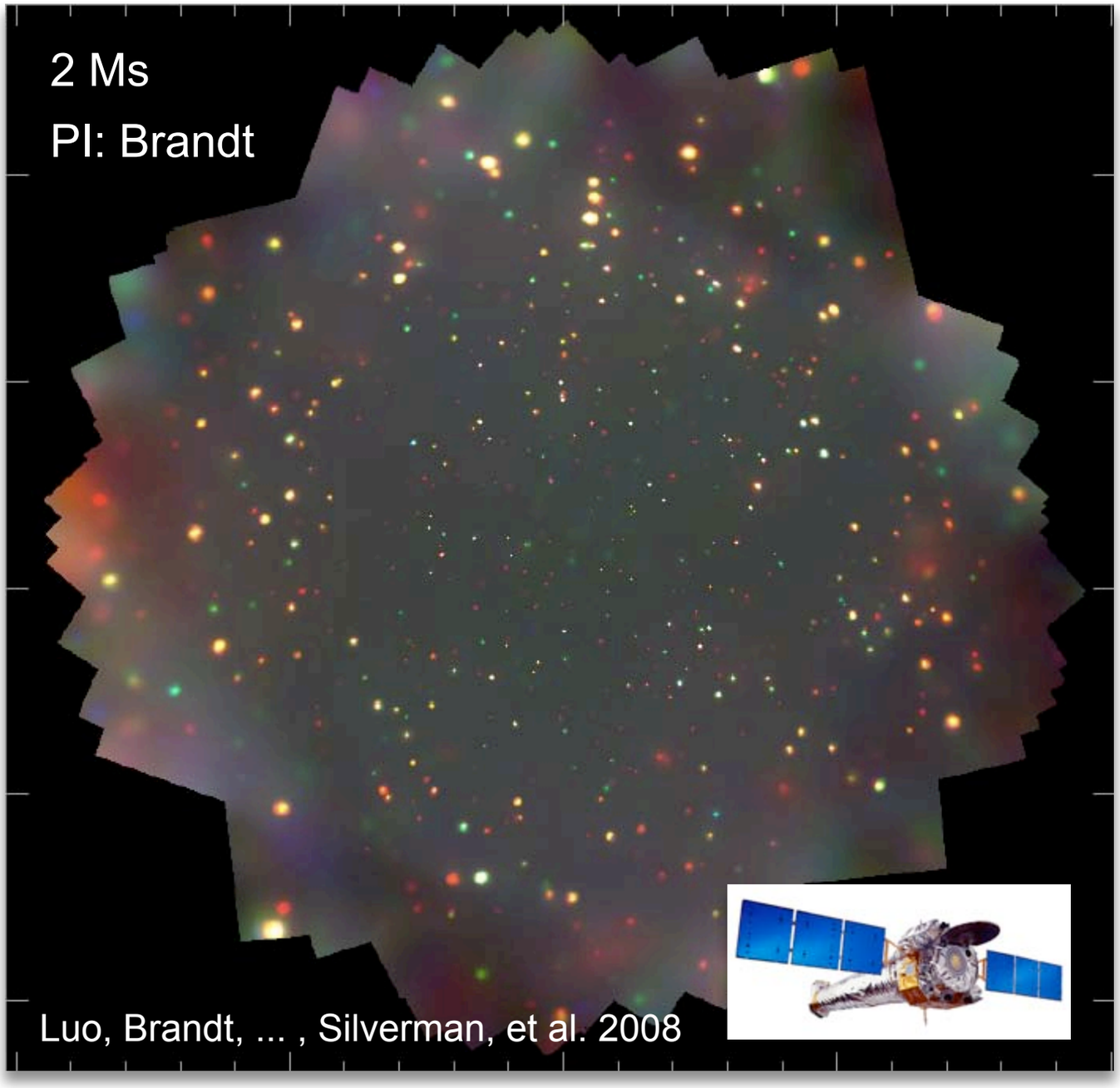


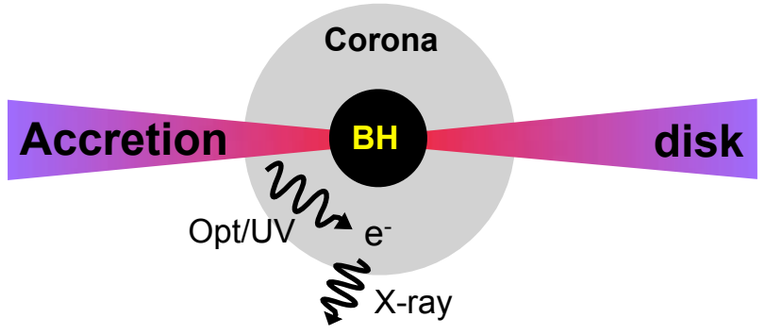
AGN hosts appear to be undergoing a transition from blue to red

X-ray emission from AGNs

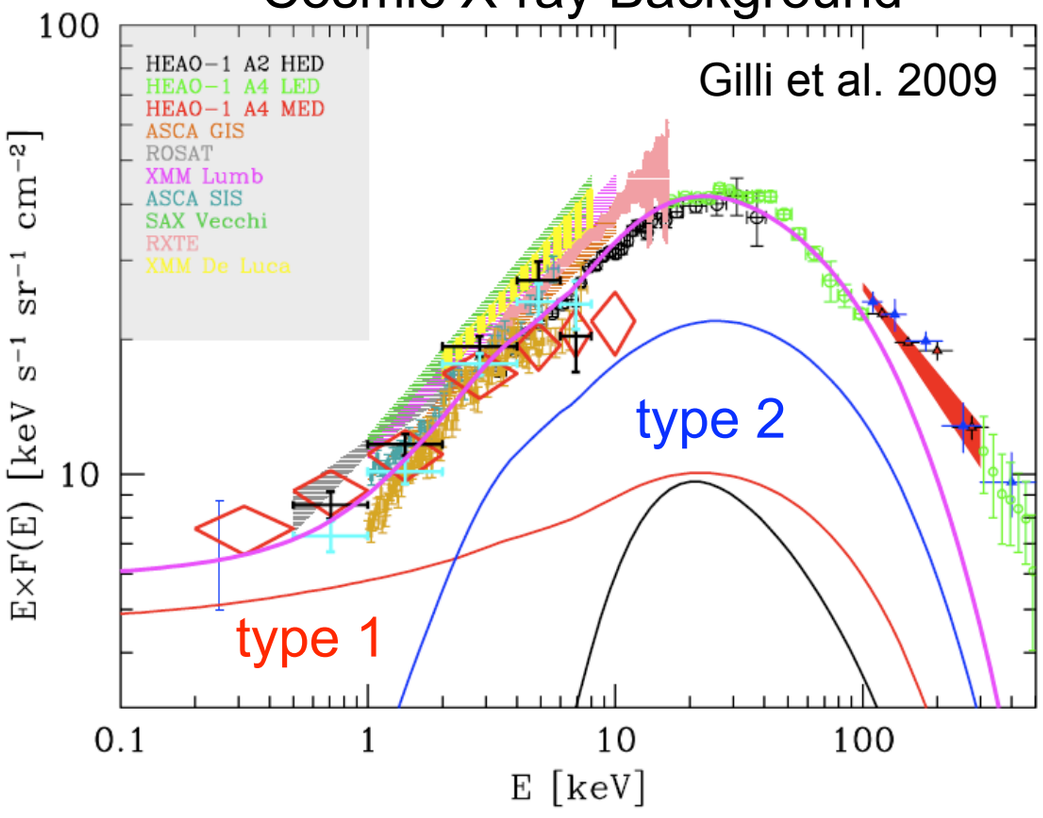
Probing obscured accretion at high redshift (z > 0.3)

Chandra Deep Field South (CDF-S)





Cosmic X-ray Background



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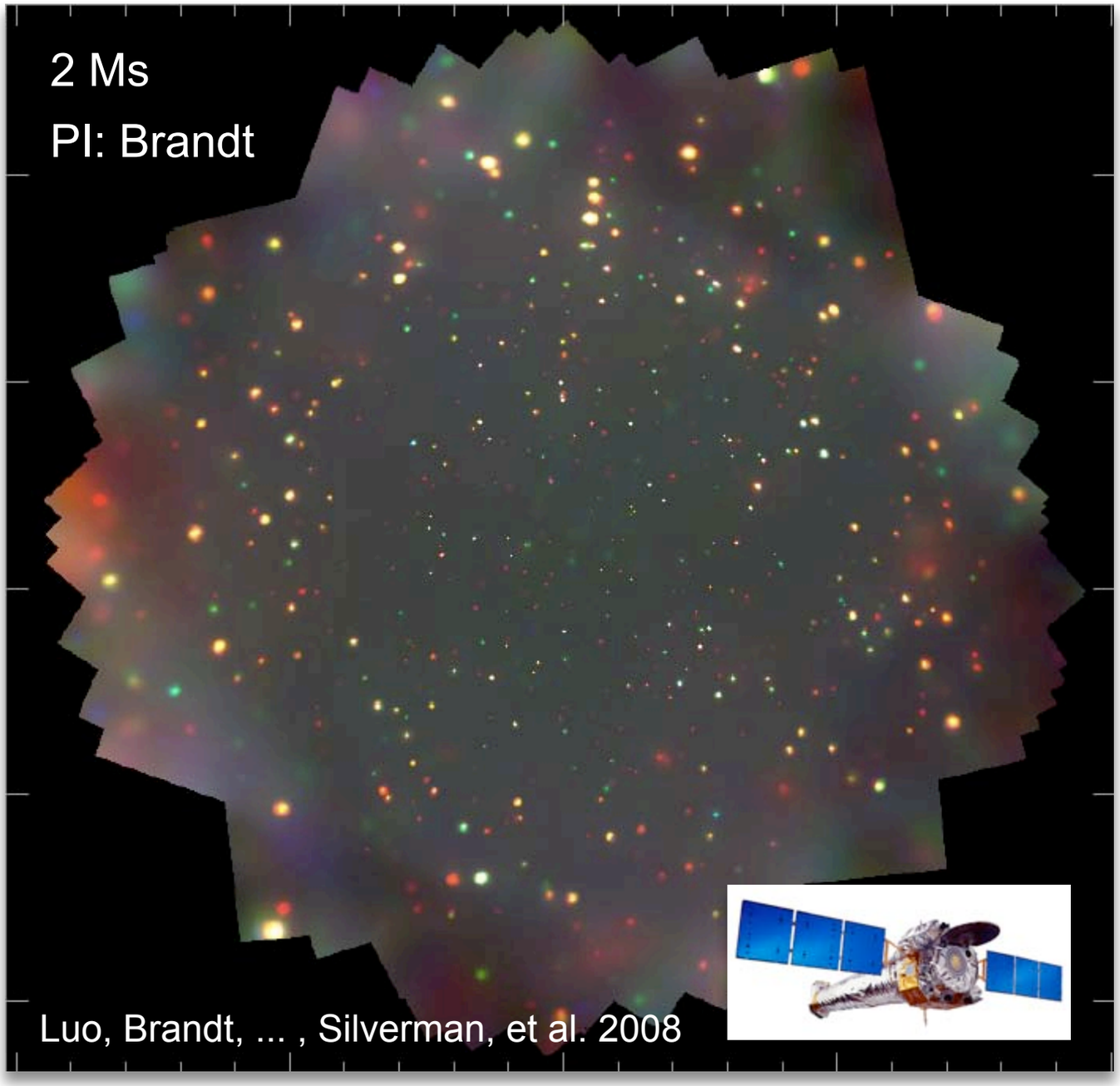
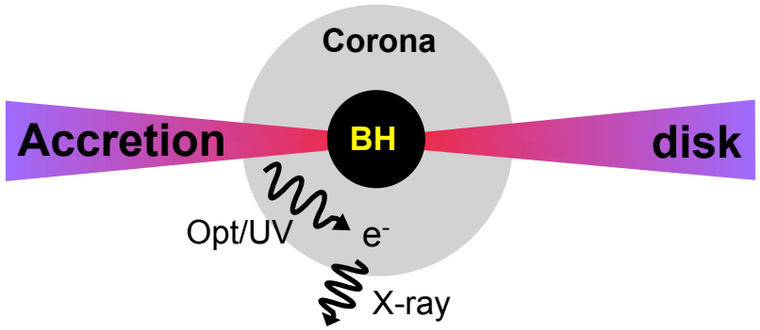
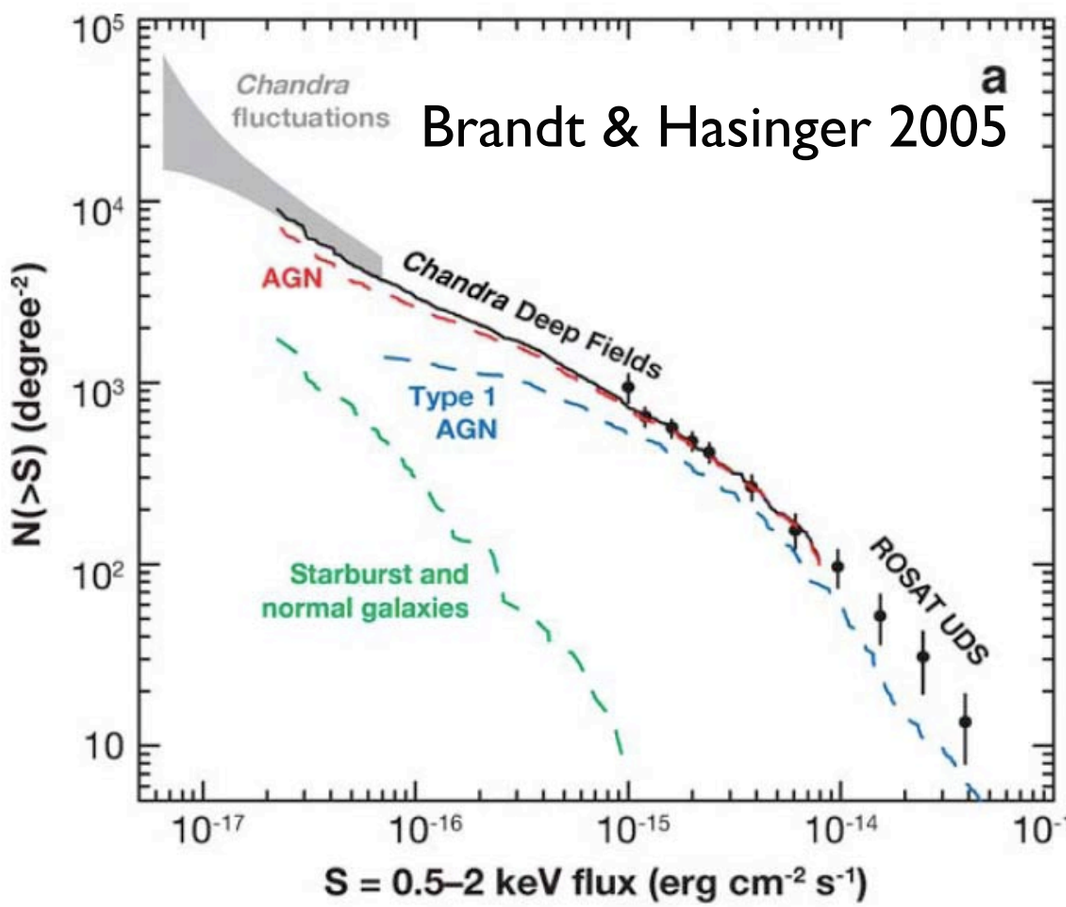
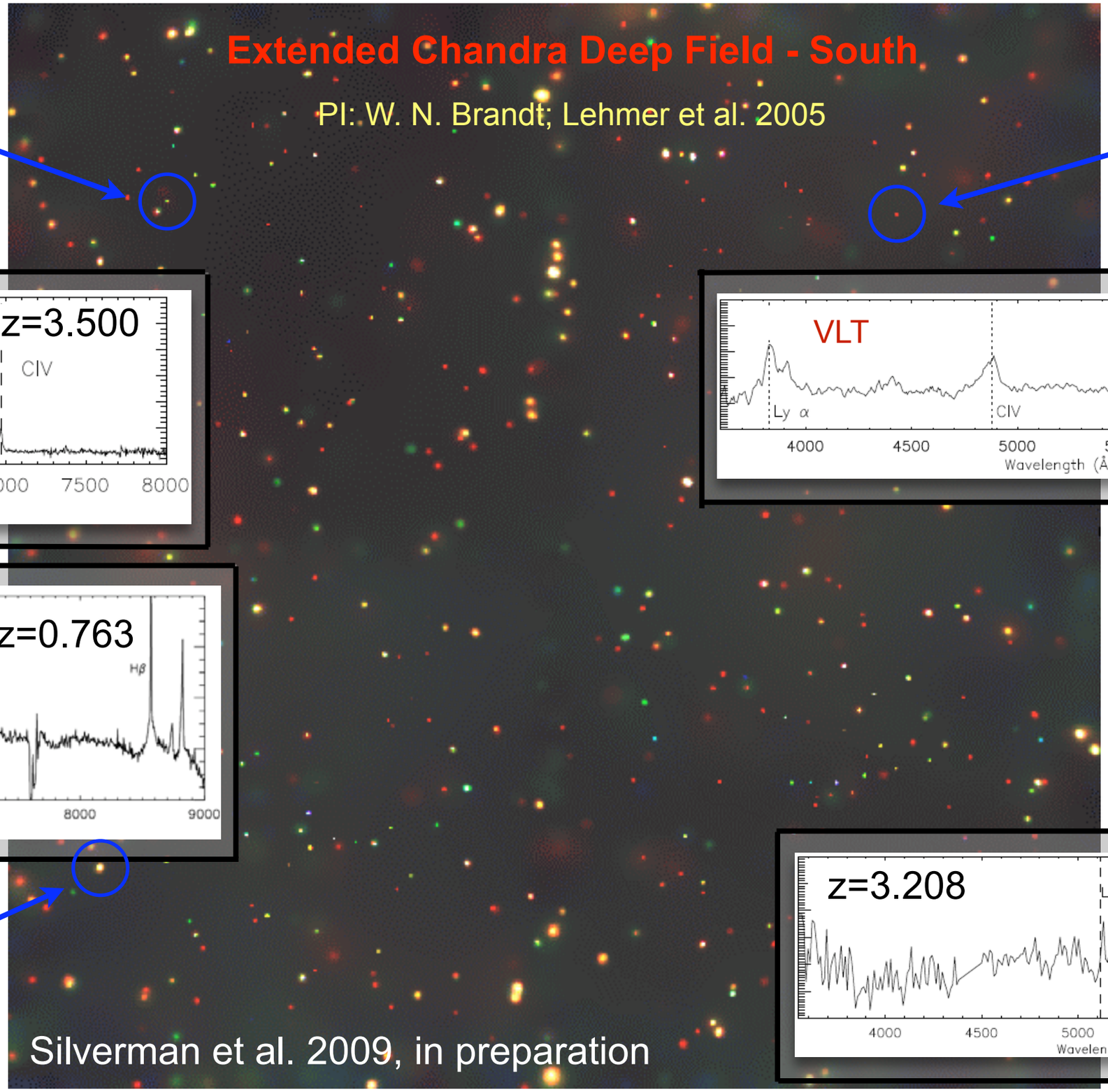


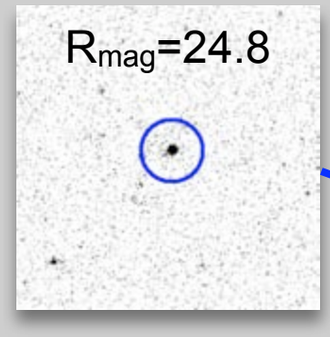




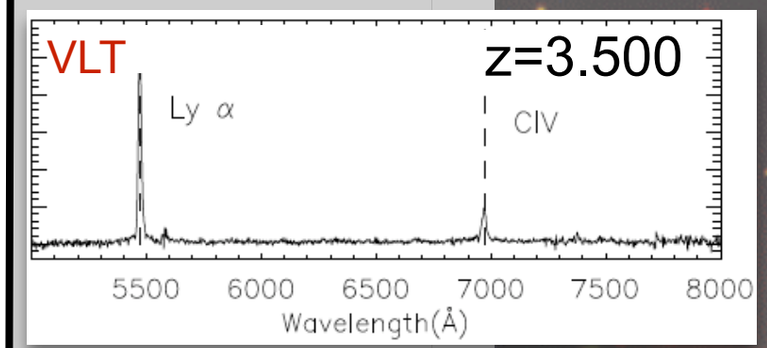
Optical identification of X-ray sources



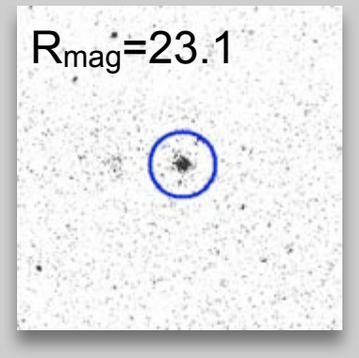
R_{mag}=24.8



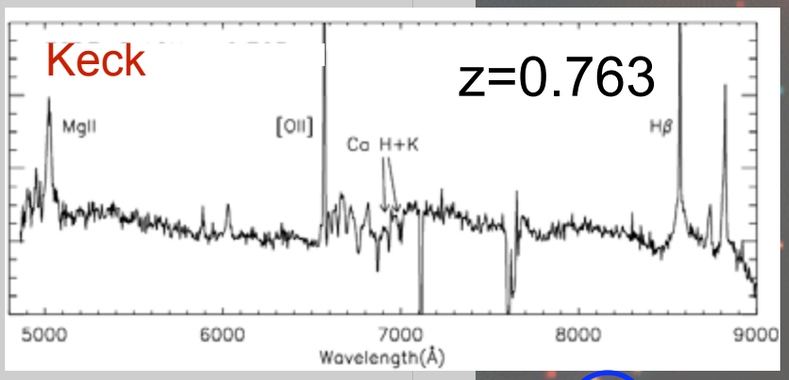
L_X=5.8x10^{44} erg s^{-1}



R_{mag}=23.1

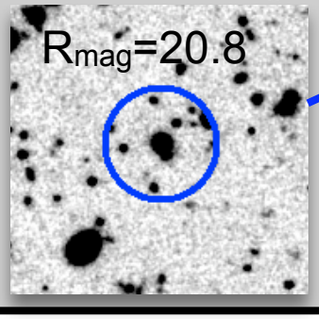


L_X=5.9x10^{43} erg s^{-1}

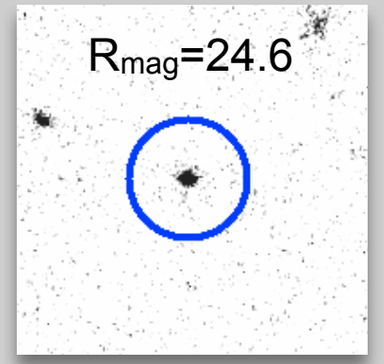


L_X=6.8x10^{43} erg s^{-1}

R_{mag}=20.8



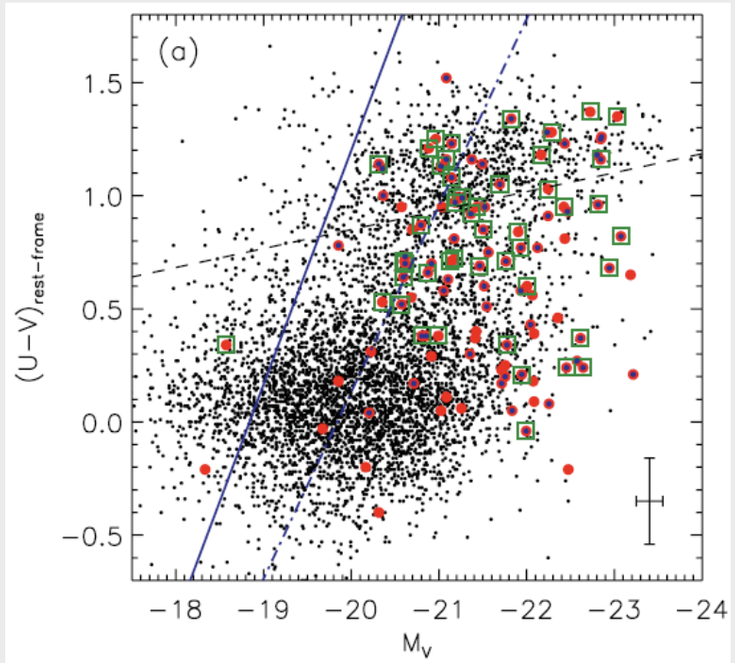
R_{mag}=24.6

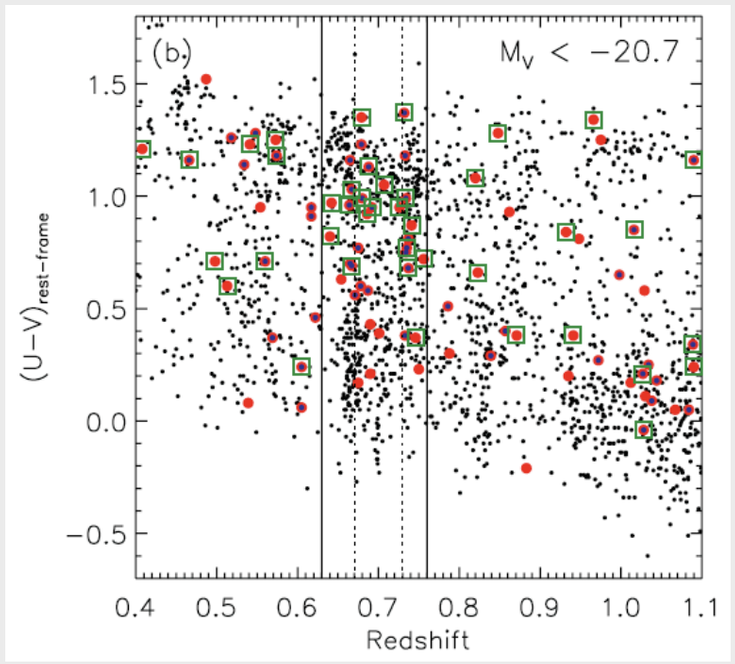


L_X=1.4x10^{43} erg s^{-1}

Host galaxy properties of X-ray selected AGN up to z~1

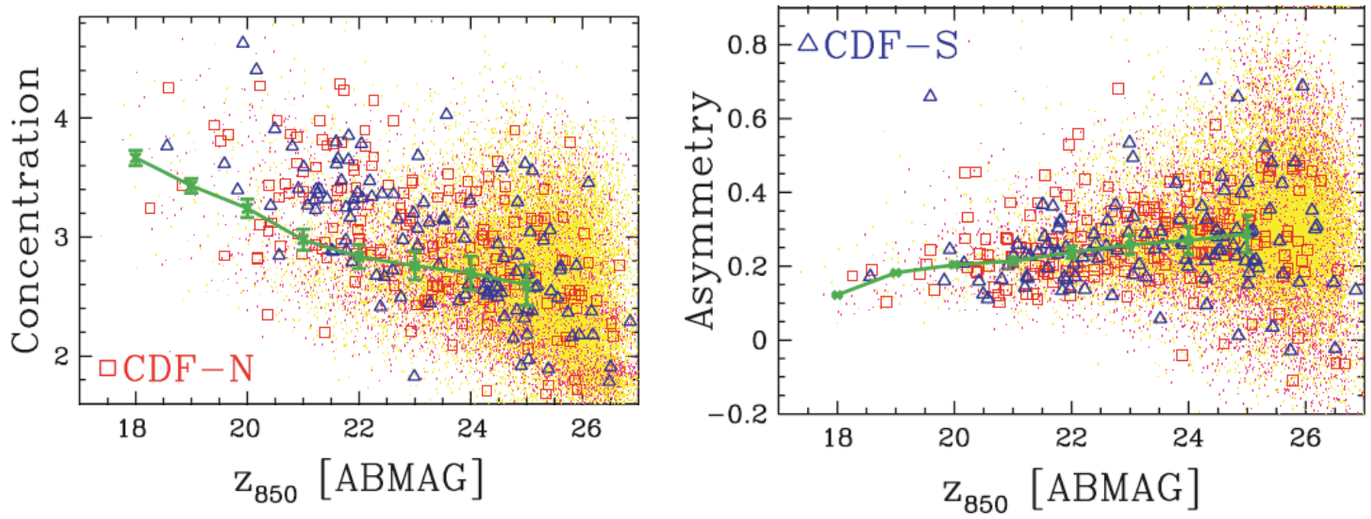
Optical color (E-CDF-S)





Silverman et al. 2008a, ApJ, 675, 1025

Morphology



Grogin et al. 2005 (see Akiyama 2005; Gabor et al. 2009)

- Host galaxies have a broad color distribution; presence in the "Green valley" (see Nandra et al. 2007; Hickox et al. 2009)
- Color evolution similar to underlying galaxy population
- Preference for bulge-dominated galaxies (e.g., Kiuchi et al. 2006)
- Lack of evidence (e.g. asymmetry) for major-merging

COSMOS

Galaxy evolution as a function of environment up to z ~ 2

PI: Nick Scoville (CalTech)

HST/ACS: i' (Scoville)

Spitzer: (Sanders)

IRAC-3.6, 4.5, 5.6 8.0μm

MIPS-24, 70, 160μm

VLA: (Schinnerer)

GALEX: (Schiminovich)

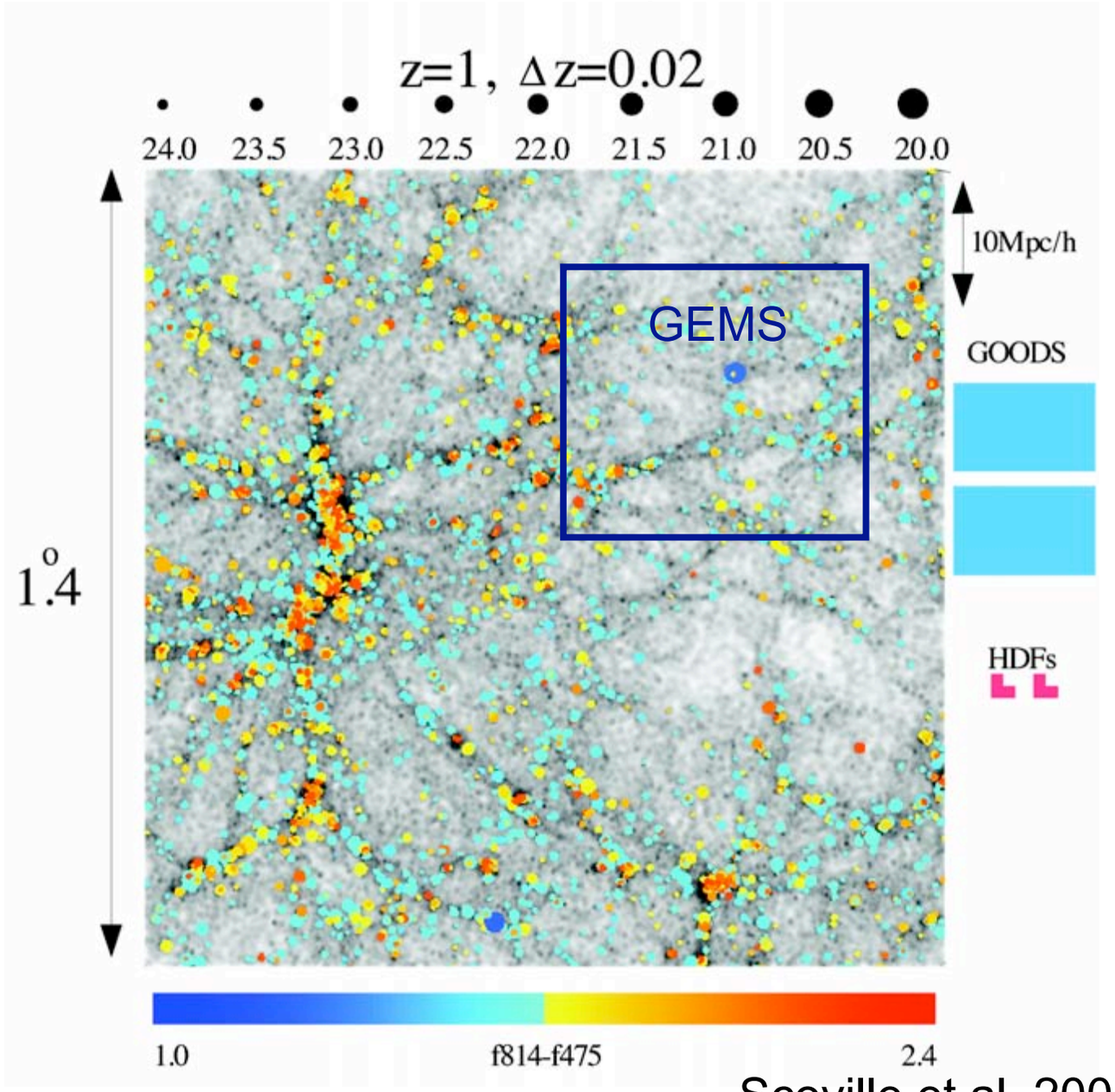
XMM: (Hasinger)

Chandra: (Elvis)

VLT: (Lilly)

Subaru: (B, V, g, r, i, z; Taniguichi)

CFHT (u,i,Ks; McCraken)



Scoville et al. 2007

Determine the relation of **ongoing** star formation (SFRs) to AGN activity ($\dot{M}_{accr}$) within the context of their local environment.

COSMOS

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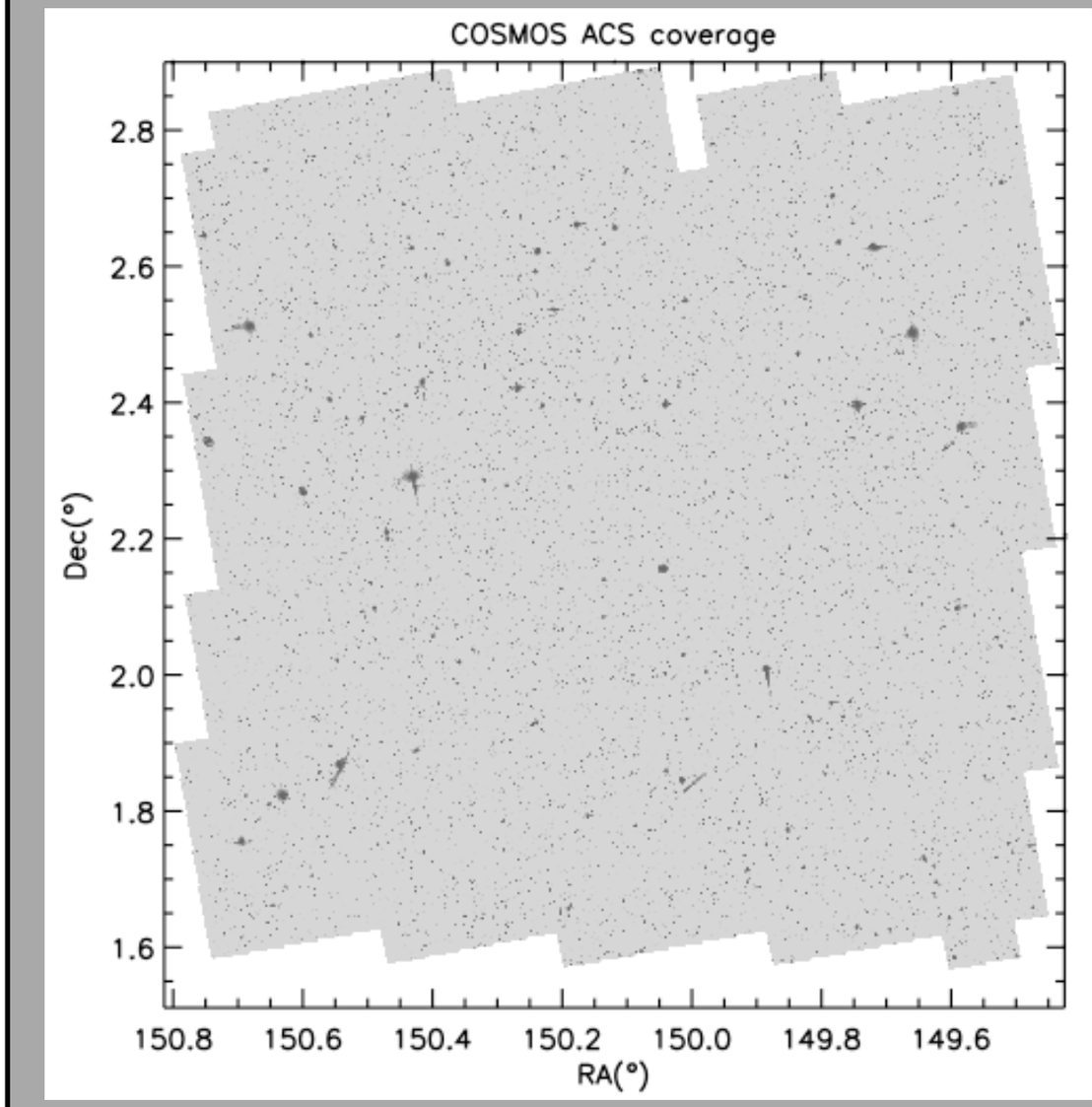

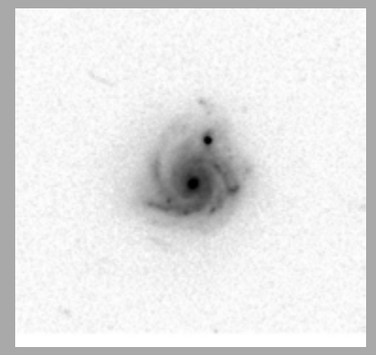

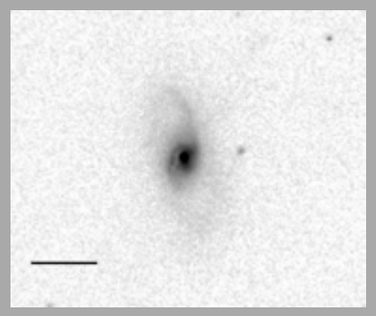

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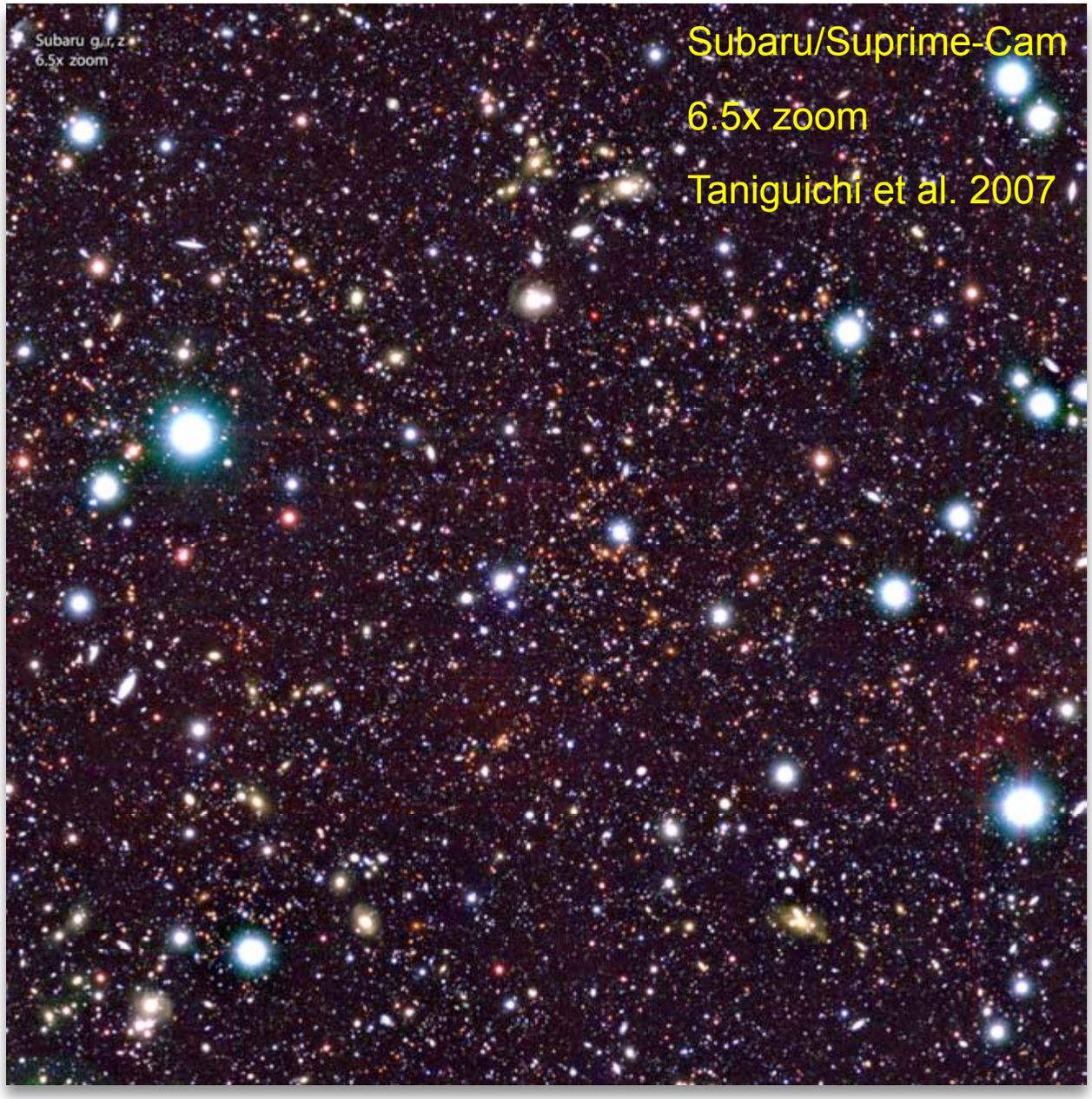
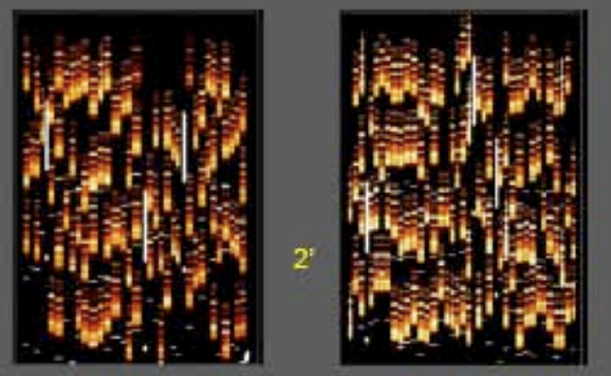
Subaru: (B, V, g, r, i, z; Taniguichi)

CFHT (u,i,Ks; McCraken)



Determine the relation of **ongoing** star formation (SFRs) to AGN activity ($\dot{M}_{accr}$) within the context of their local environment.



zCOSMOS DPT institutes

ETH Zurich

LAM Marseille

LAOMP Toulouse

INAF Milano

INAF Bologna

MPE Garching

Very hard to reliably automate redshift measurements from faint spectra → ~ 30 FTE effort

zCOSMOS (600 hrs on VLT, started April 2005):

- about 20,000 spectra $0.1 < z < 1.4$ in "-bright": **$I_{AB} < 22.5$ over 1.7 deg^2**
- about 10,000 spectra $1.4 < z < 3.5$ in "-deep": **colour-selection, $B < 25$, over 0.9 deg^2**
- designed for high success rate (~ 90% in bright, ~ 80% in deep)
- and high sampling rate (~ 70%) with multiple passes (8 in bright, 4 in deep)
- with velocity accuracy of 100 kms^{-1} in bright, 300 kms^{-1} in deep
- duplication in spectral data reduction, redshift identification and other measurements

zCOSMOS 10k catalog

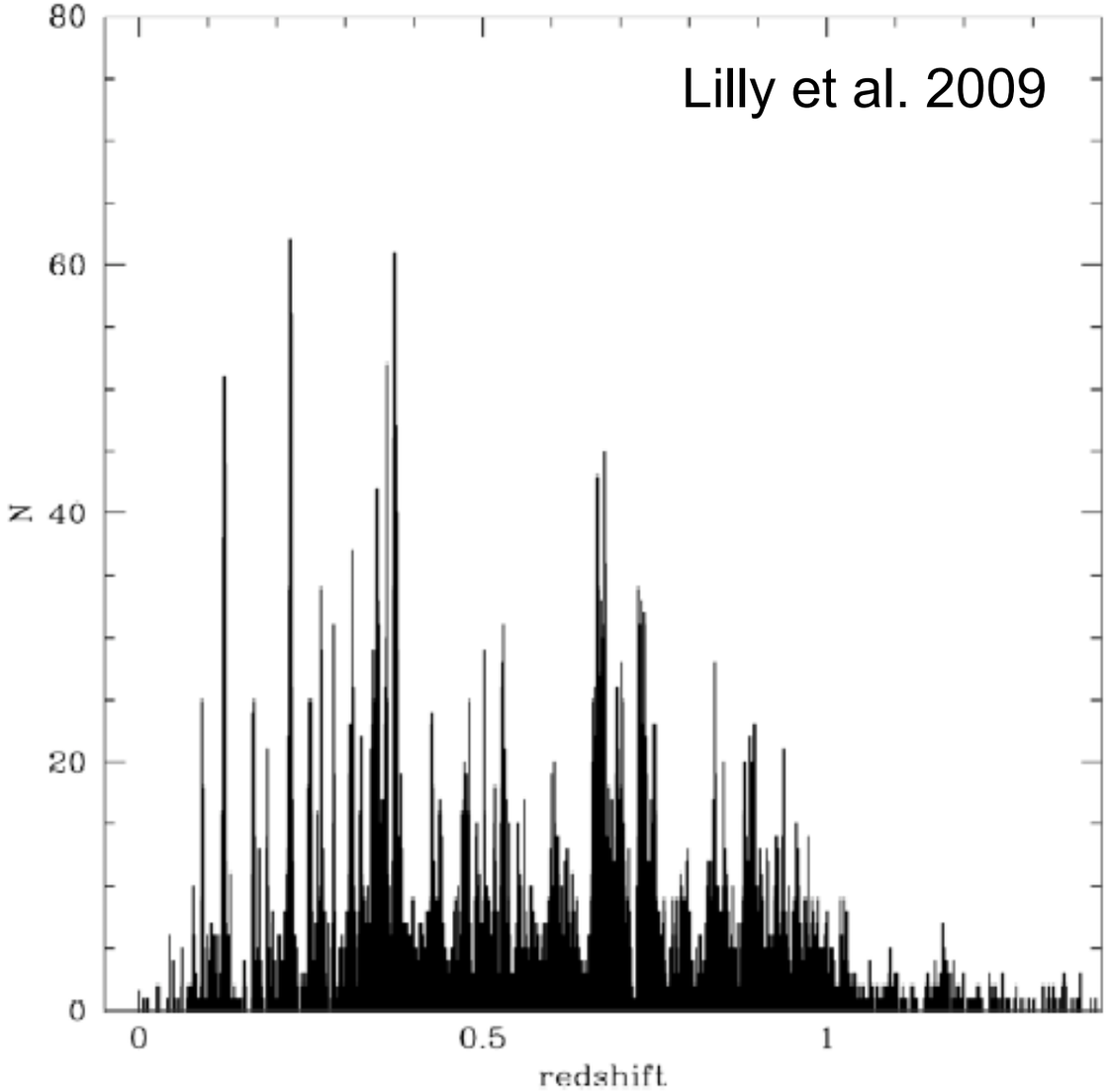
'Bright program'

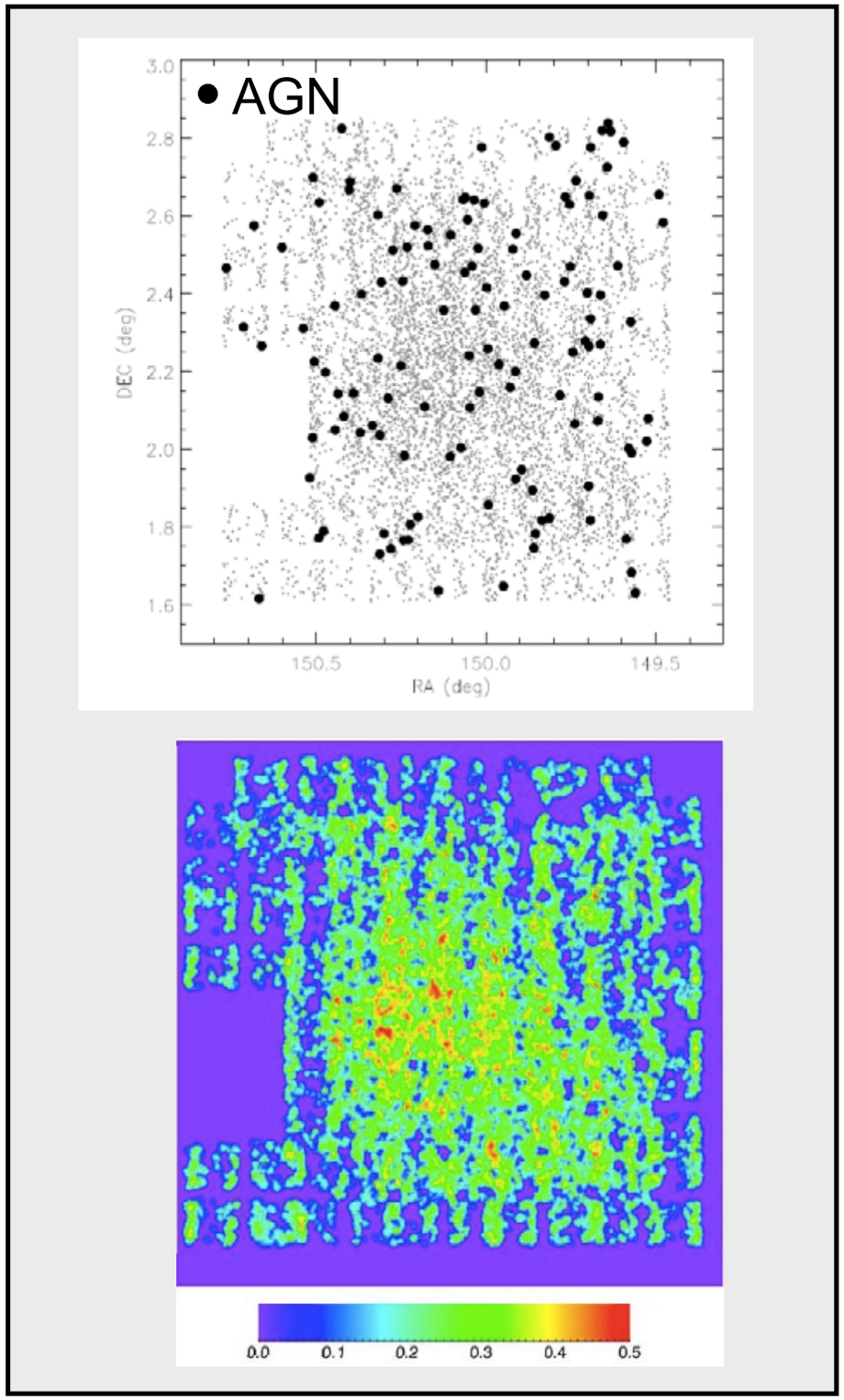
$I_{AB} < 22.5$

1.7 deg2

~5500-9600 Å

z < 1.2





zCOSMOS 10k catalog

'Bright program'

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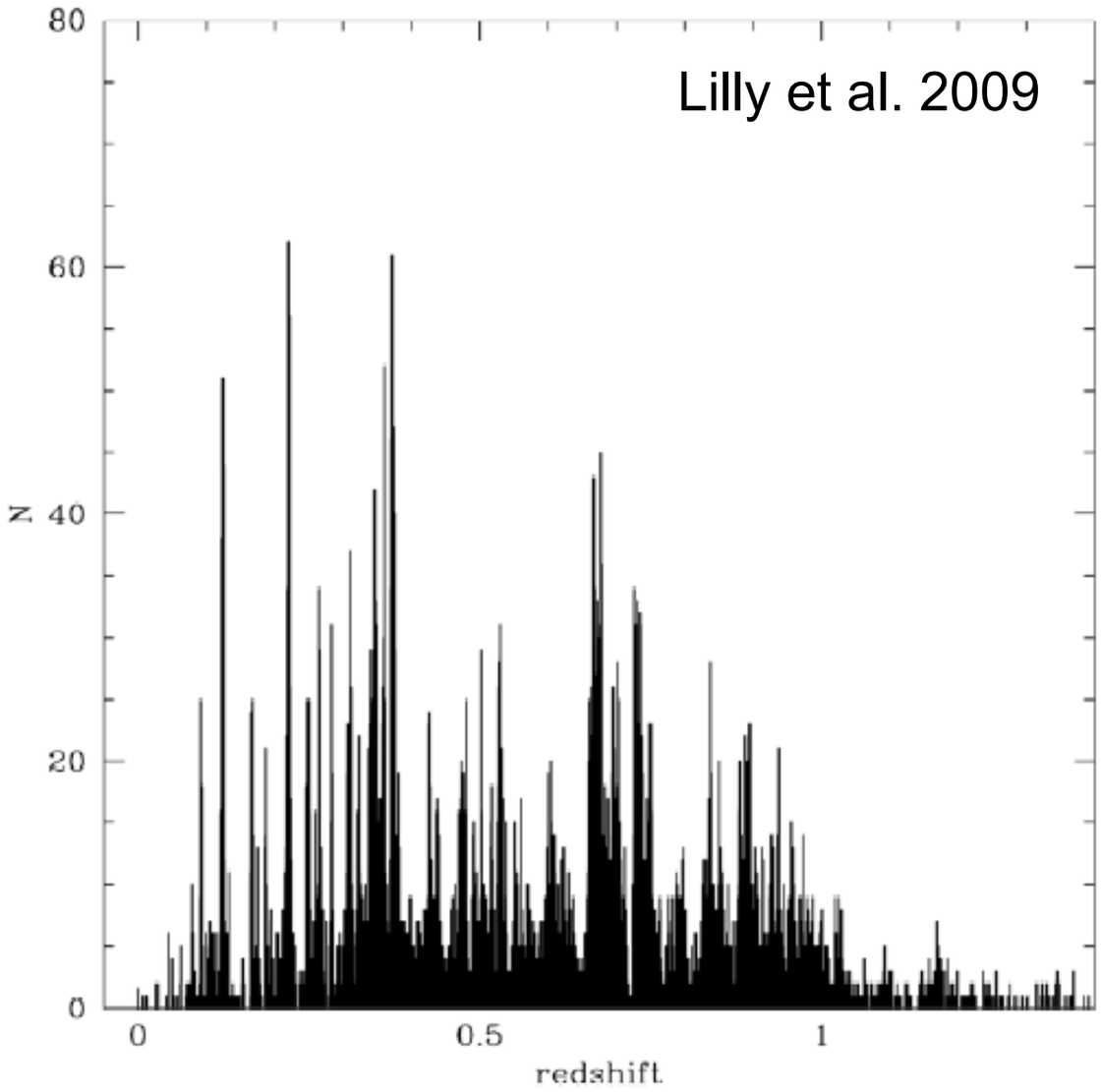


Select studies to date:

"*The Dependence of Star Formation Activity on Stellar Mass Surface Density and Sersic Index*" Maier et al. 2009, ApJ, 694, 1099

"*An optical group catalogue to z = 1 from the zCOSMOS 10k sample*" Knobel et al. 2009, ApJ, in press, arXiv:0903.3411

"*The density field of the 10k zCOSMOS galaxies*" Kovac et al. 2009, ApJ, submitted, arXiv:0903.3409

"The Close Environment of 24 µm Galaxies at 0.6 < z < 1.0 in the Cosmos Field" Caputi et al. ApJ, 691, 91

To be submitted soon:

"*Role of stellar mass in the color-density relation up to z ~1*" Cucciati et al. 2009

"*Galaxy stellar mass function up to z~2*" Bolzonella et al. 2009

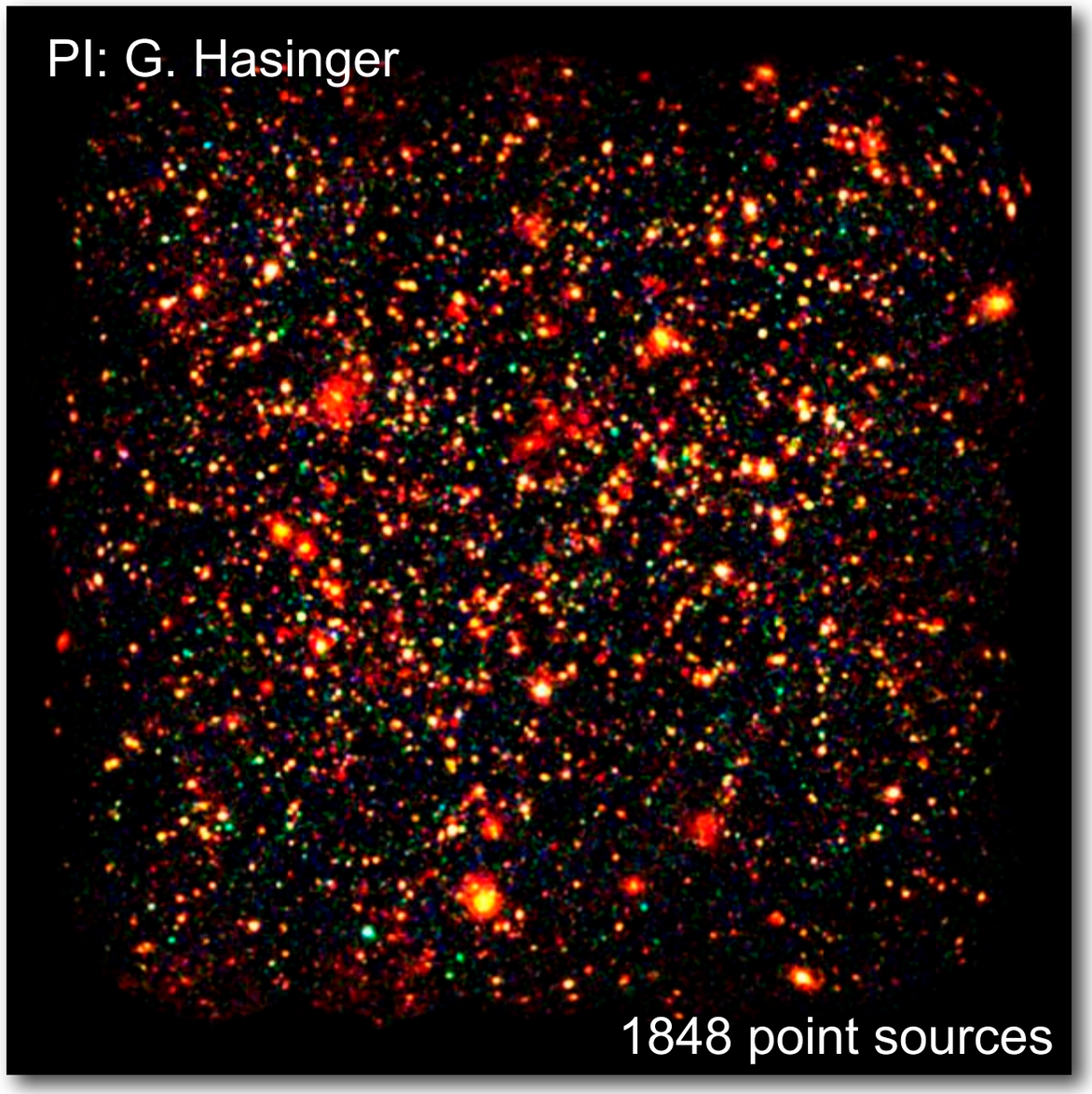
"*Unveiling galaxy bimodality in the Galaxy Stellar Mass Function and exploring its evolution with redshift*" Pozzetti et al. 2009

"*Group environment and galaxy colors up to z ~1*" Iovino et al. 2009

"*Build-up of the morphology-density relation up to z~1*" Tasca et al. 2009

"*Close kinematic pairs in zCOSMOS*" Kampczyk et al. 2009

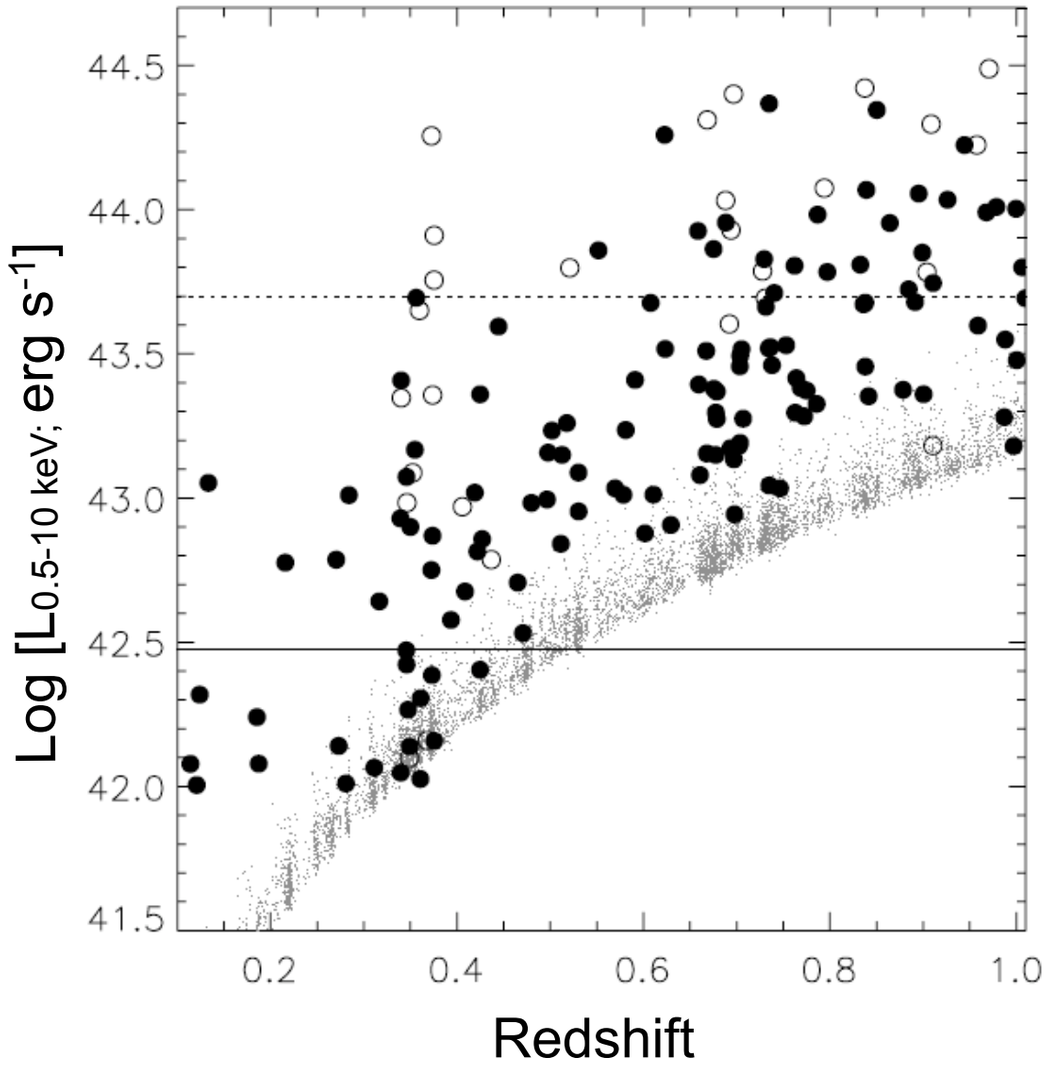
XMM/COSMOS



Hasinger et al. 2007; Cappelluti et al. 2007, 2009

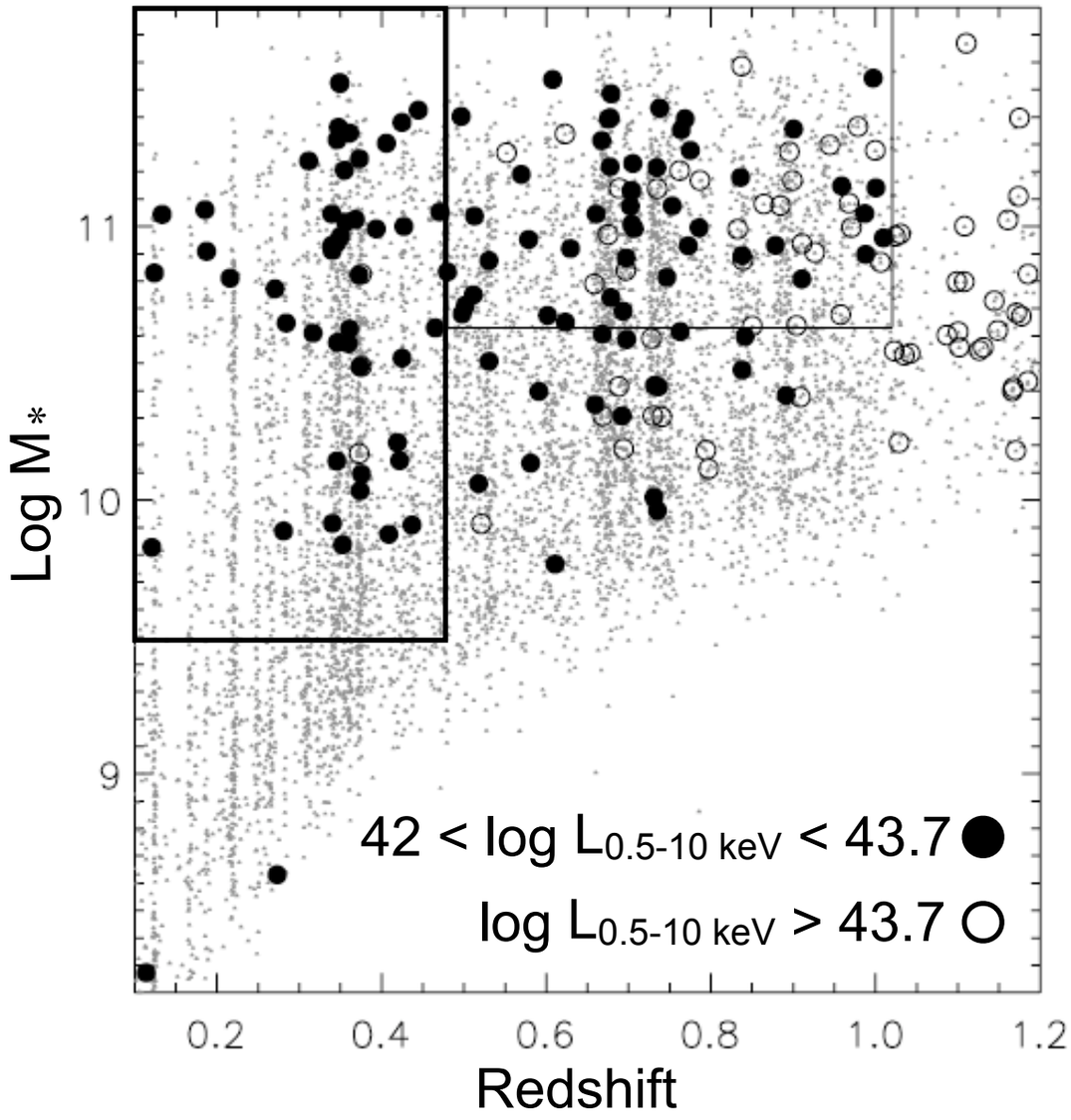
$f_{0.5\text{-}2.0\ keV} >$ 5 x 10^{-16} erg cm^{-2} s^{-1} (Soft band)

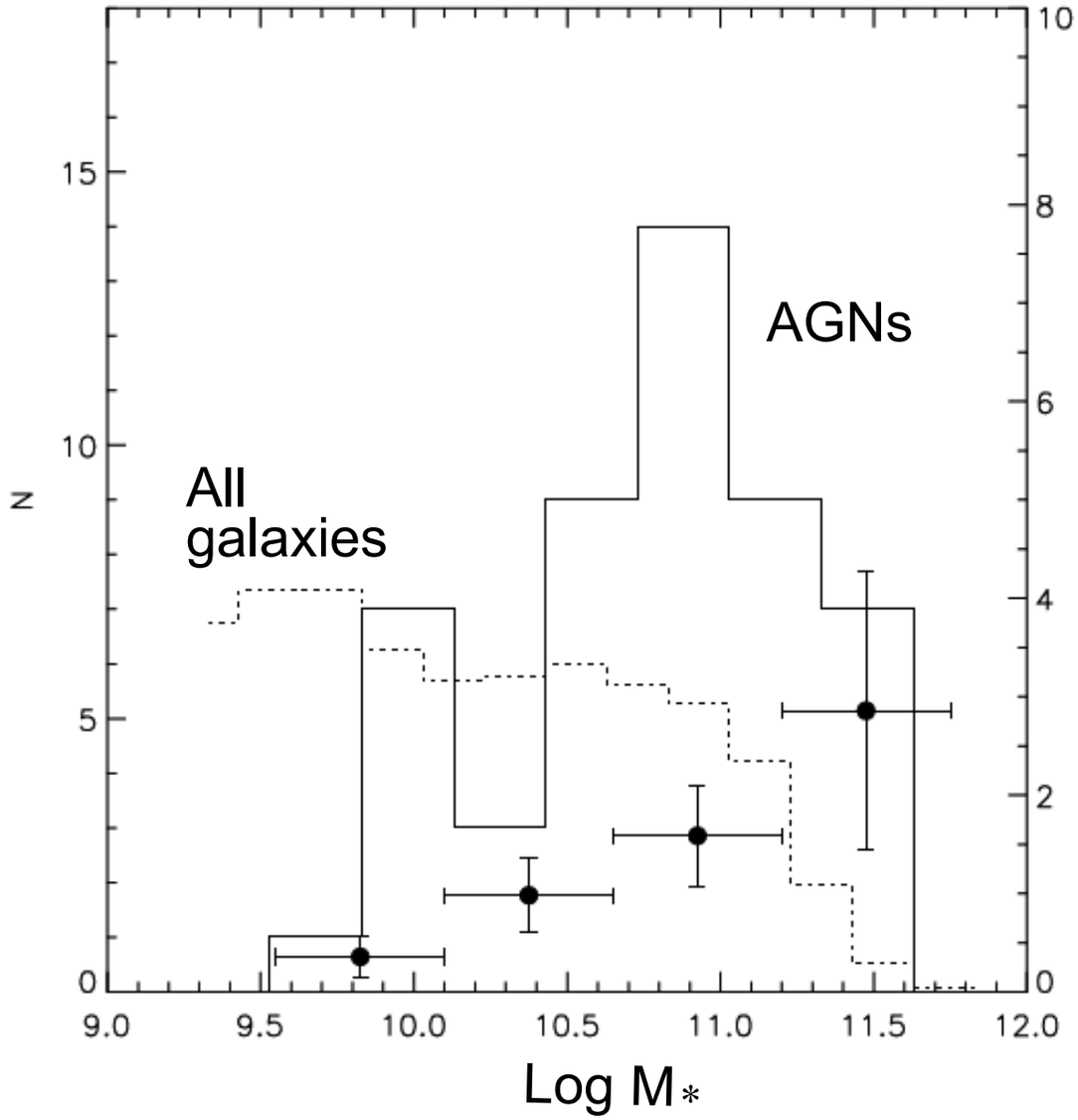
$f_{2.0\text{-}10\ keV}$ > 2 x10^{-15} " " (Hard bard)



152 AGNs (0.1 < z <1) identified by zCOSMOS/10k having $L_X > 10^{42}$ erg s^{-1}

Host galaxy stellar mass





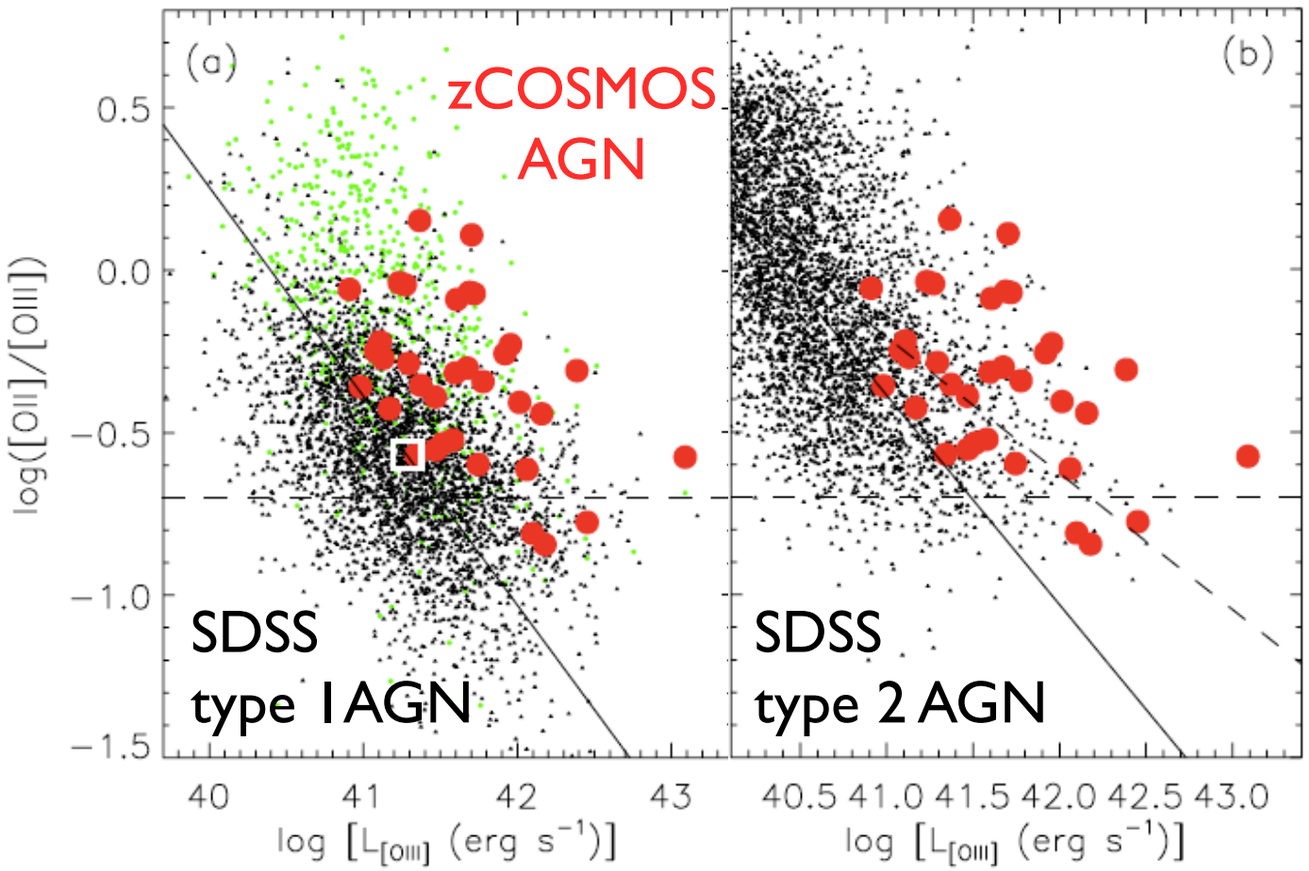
AGN activity rises with host galaxy mass

Agreement with SDSS (Kauffmann et al. 2003; Best et al. 2005)

Star formation rates of AGN hosts

[OII]λ3727 as a SFR indicator (Ho et al. 2005)

- Not yet exploited for AGN hosts
- [OII] mainly attributed to host galaxy (see Croom et al. 2002)
- Quasars exhibit low SFRs (a few $M_\odot$ yr^{-1}). Quenching at low redshift?



Method:

I. PLATEFIT_VIMOS (Lamareille et al. 2008)

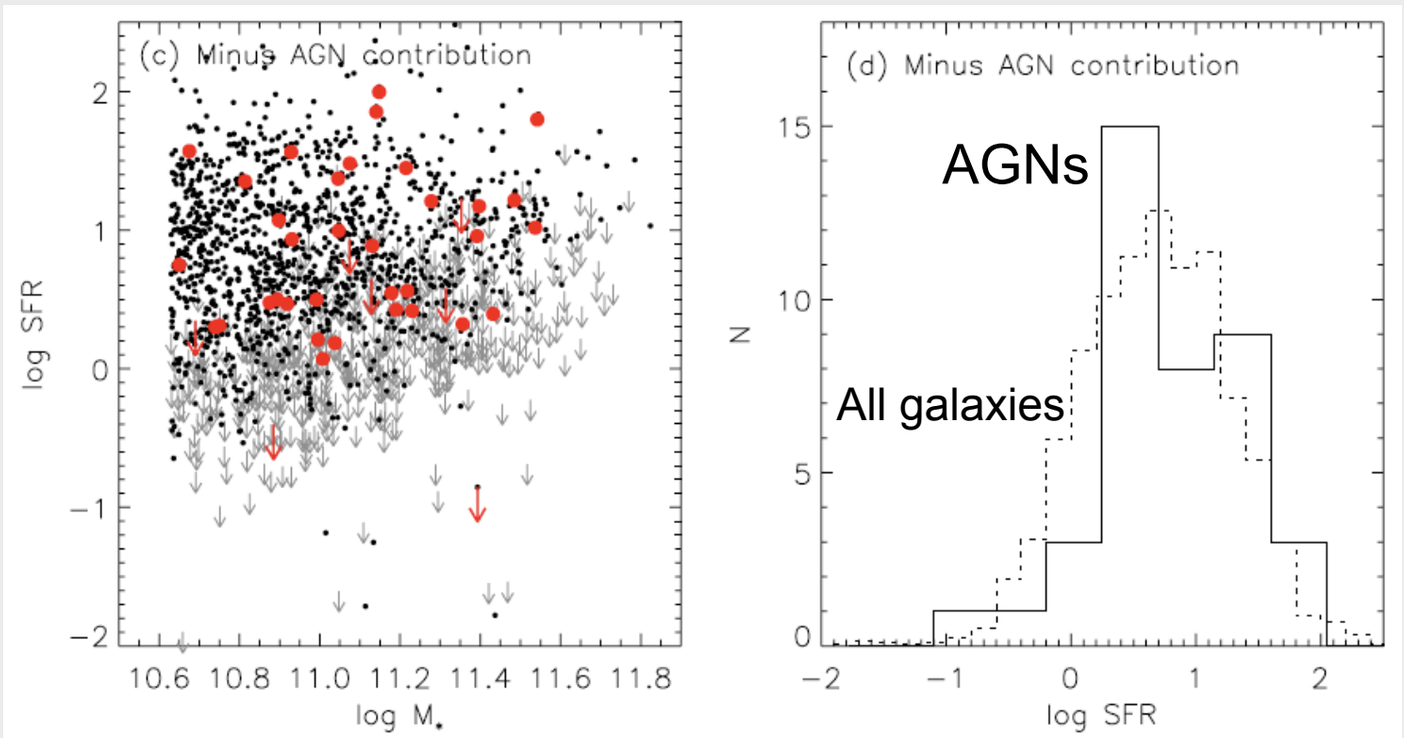
- automated spectral measurements
- [OII]λ3727, [OIII]λ5007, Hα, Hβ, [NII]

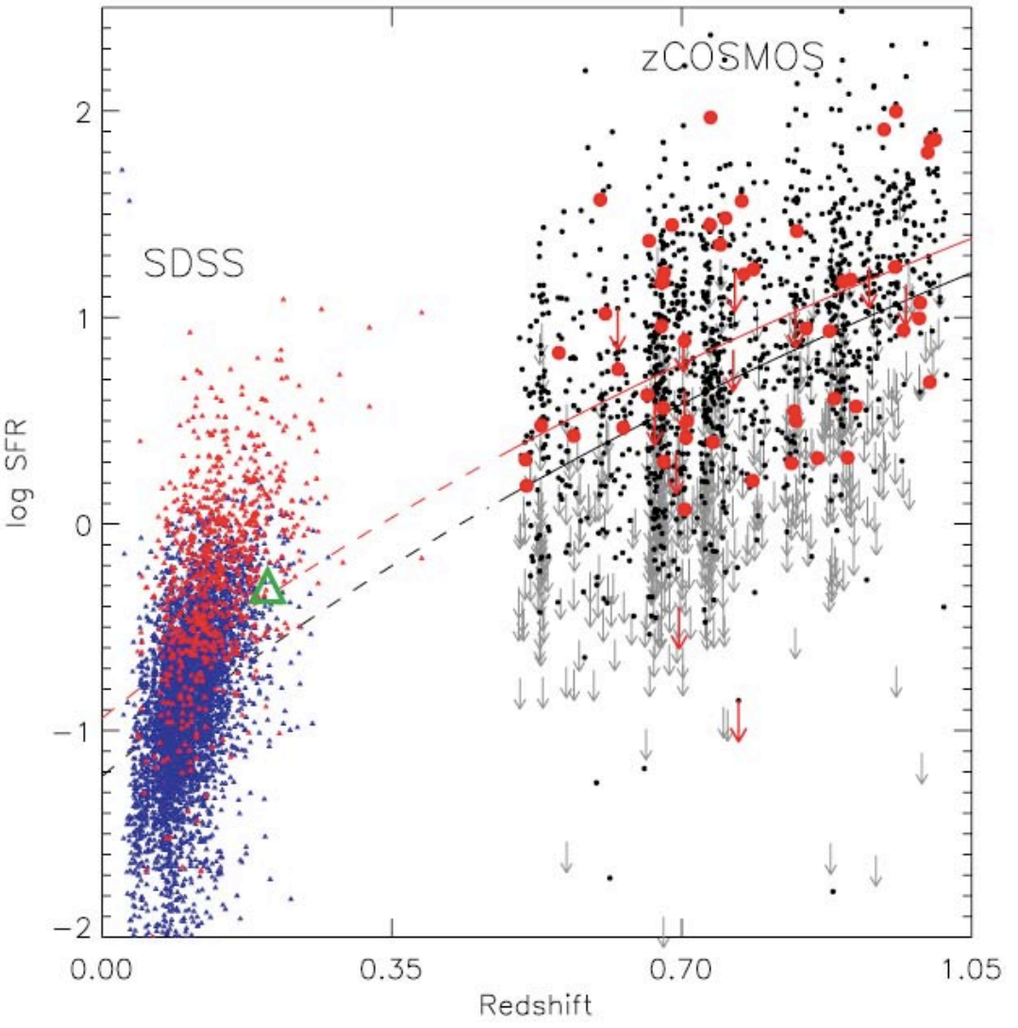
II. Removal of AGN contribution; assume

- [OIII]λ5007 purely AGN dominated (Kauffmann et al. 2003)
- $[OII]_{AGN}/[OIII]_{AGN}=0.2$ (Minjin Kim, L. Ho et al. 2006)
- $A_V=0.8$ (Kewley et al. 2006)
- At z>0.85, infer [OIII] from correlation with $L_{2\text{-}10\ keV}$ (Heckman et al. 2005, Panessa et al. 2006)

III. $\log SFR = \log L_{[OII]} - 41 - 0.2*M_B - 3.43$ (Moustakis et al. 2006)

Star formation rates of AGN hosts

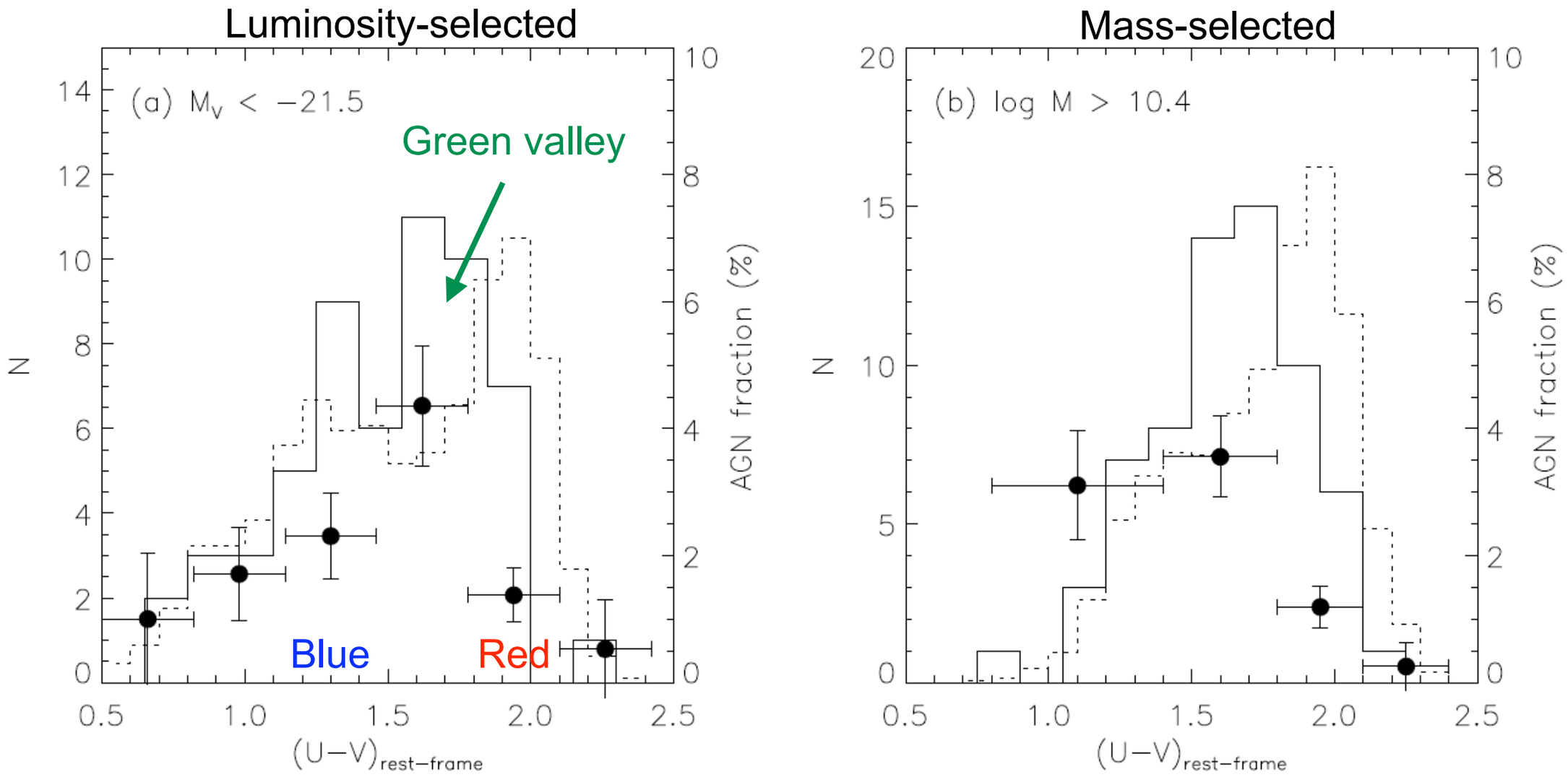




- Significant levels of star formation: $\sim 1 < SFRs < 100\ M_{\odot}\ yr^{-1}$
- Similar evolution to the star-forming galaxy population
- Consistent with low SFRs in SDSS AGNs ($z < 0.3$)

Silverman et al. 2009b, ApJ, 696, 396

Are AGNs associated with transitional galaxies



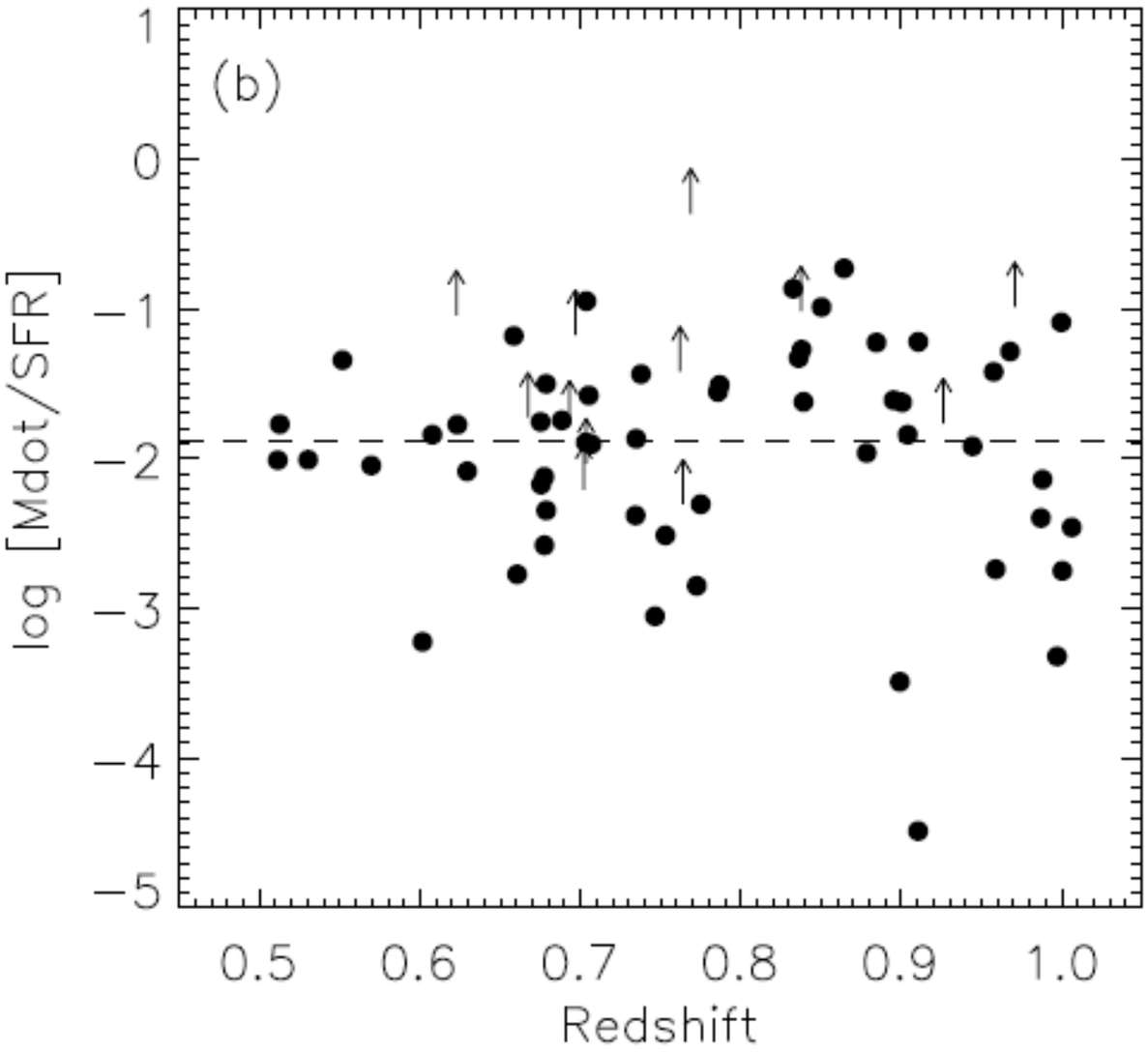
SDSS: Martin et al. 2007; Salim et al. 2007; Schawinski et al. 2007; Westoby et al. 2007

X-ray surveys: see Nandra et al. 2007; Silverman et al. 2008; Georgakakis et al. 2008; Schawinski et al. 2009

Must account for the low mass-to-light ratio of ‘blue cloud’ galaxies

Silverman et al. 2009b, ApJ, 696, 396

Co-evolution of accretion and star formation



- Constant ratio with redshift
- $\langle \dot{M}_{accr}/SFR \rangle \sim 10^{-2}$ [A factor of 10x higher than M_{BH}-M_{bulge} relation]
- Intermittant scenario with an AGN duty cycle 10x shorter than star formation

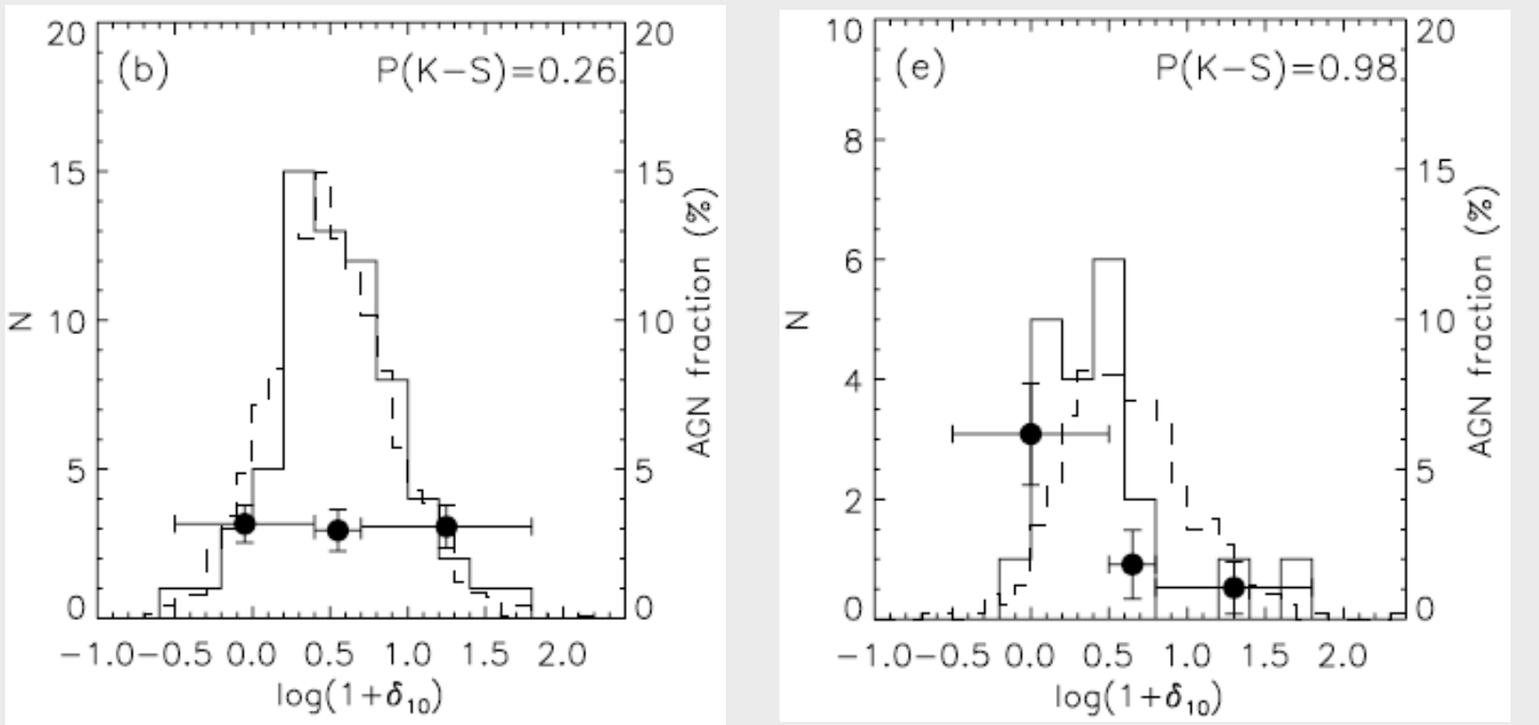
Silverman et al. 2009b, ApJ, 696, 396

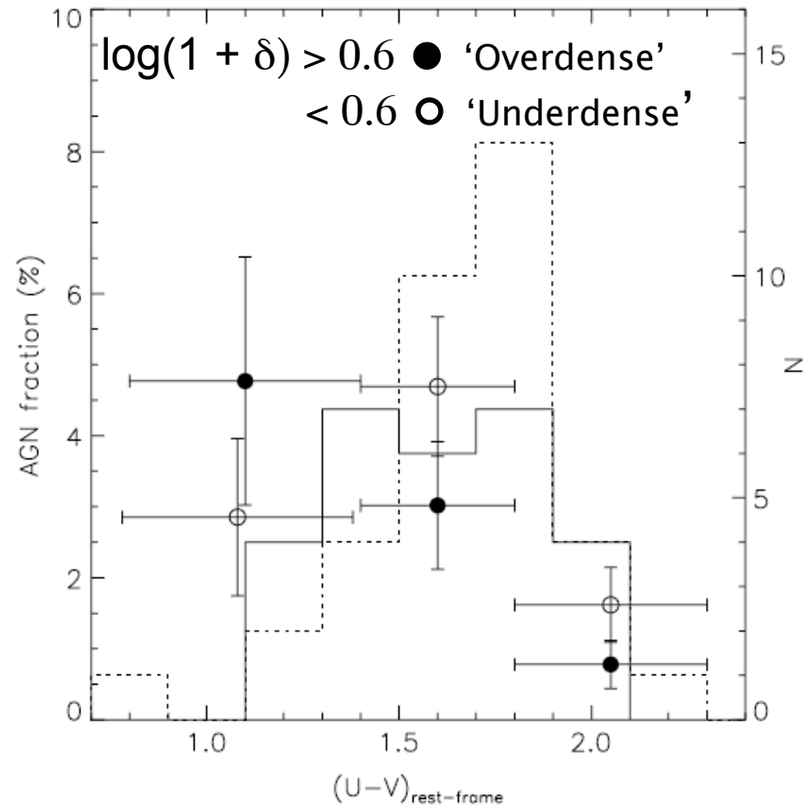
Environments of AGNs

Zurich developed density estimator (Kovac et al. 2009, arXiv:0903.3409)

- Nearest neighbor approach (e.g., 5th,10th)
- spectroscopic (10k) + photometric (30k) redshifts
- flux and volume limited tracers
- Projected-density (± 1000 km s^{-1})
- Overdensity (δ): $1 + \delta = \rho/\langle\rho\rangle$

log $M_* > 10.4$ | log $M_* > 11$





Silverman et al. 2009a, ApJ, 695, 171

- Environments similar to star-forming galaxies
- AGNs in massive hosts (log $M_* > 11$) prefer underdense regions

✳ resolves seemingly disparate results from the SDSS (Miller et al. 2003; Kauffmann et al. 2004)

z: 0.4 ~ 0.55

z: 0.55 ~ 0.7

z: 0.7 ~ 0.85

z: 0.85 ~ 1.0

zCOSMOS

ETH Zurich

K. Kovac, Y. Peng

Conclusions

- **Two basic requirements for a galaxy to harbor an accreting SMBH**
  - ✦ a massive host galaxy
  - ✦ a sufficient fuel supply
    - substantial levels of star formation (1-100 $M_\odot$ yr^{-1}) in zCOSMOS galaxies hosting AGN
    - no evidence for the quenching of star formation attributed to AGN feedback

- **Mutual decline in star formation and supermassive black hole accretion**
  - ✦ shifts the evidence for co-evolution scenario to smaller physical scales (i.e., within the same galaxies)
  - ✦ intermittant SMBH growth on time scales ~10^8 yr

- **AGNs reside in environments similar to star-forming galaxies**
  - ✦ physical processes such as galaxy harrassment and/or tidal stripping are influential in dense environments

Where is the star formation occurring (bulge vs. disk)?

What about the more luminous quasars and role of mergers at z ~ 2?