Lecture 3

# The hosts of AGN and their environments

- Evidence for stars in nuclear and circumnuclear regions of AGN
- Chemical abundances
- Host galaxies and their environments
- Connection between BH mass and galaxy mass
- AGN and galaxy formation and evolution

Itziar Aretxaga (INAOE), @El Escorial, Dec 2007

# Low-z QSOs: host properties

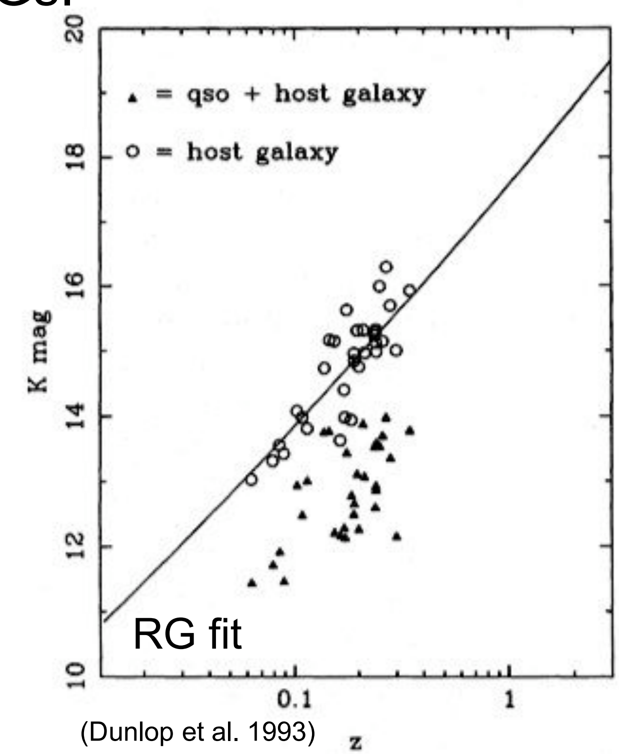
If low-L AGN have a dichotomy between RL and RQ AGN host galaxies:

RQ tend to reside in early-type S gals

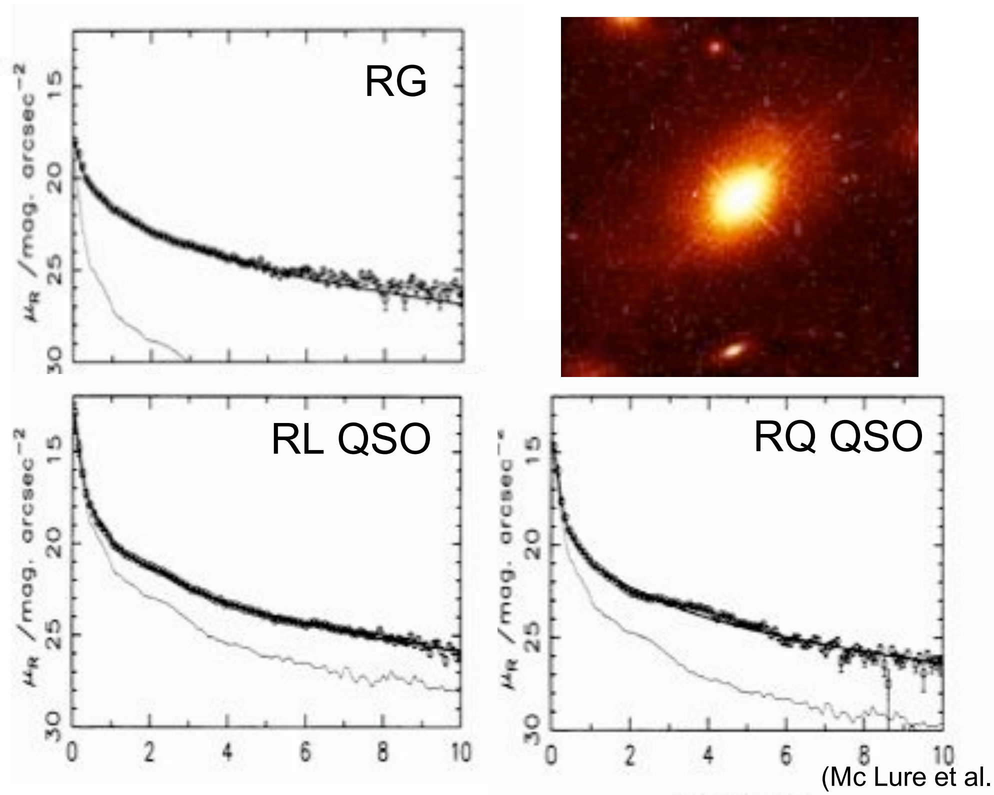
RL tend to reside in E gals

while SBs tend to reside in late-type S gals (e.g. Heckman 1985)

Luminous (M<-24, z<0.4) QSO hosts (both RL & RQ) reside in E gals L≥2L$_*$ with ~10 kpc scalelengths (Dunlop et al. 1993, Disney et al. 1995, Taylor et al. 1996, Hopper et al. 1997, McLure et al. 1999 —contested by Lewave et al. 2007), and follow the K-z relation of RGs.



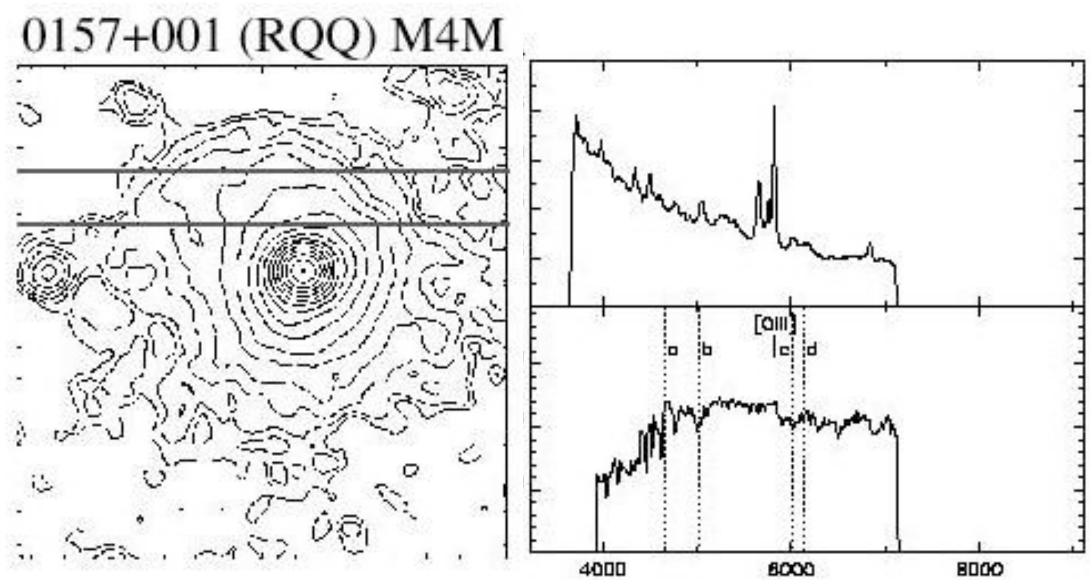
(Dunlop et al. 1993)



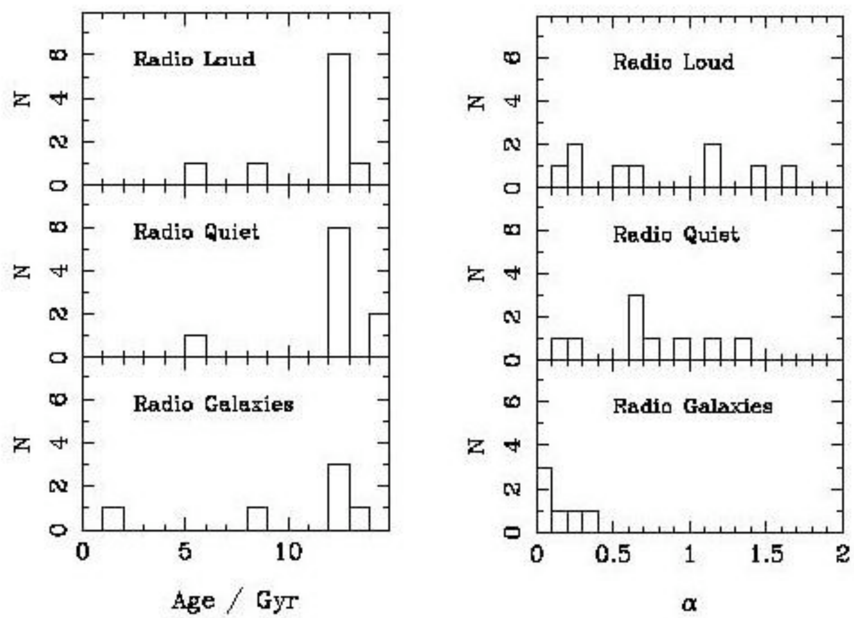
(Mc Lure et al. 1999)

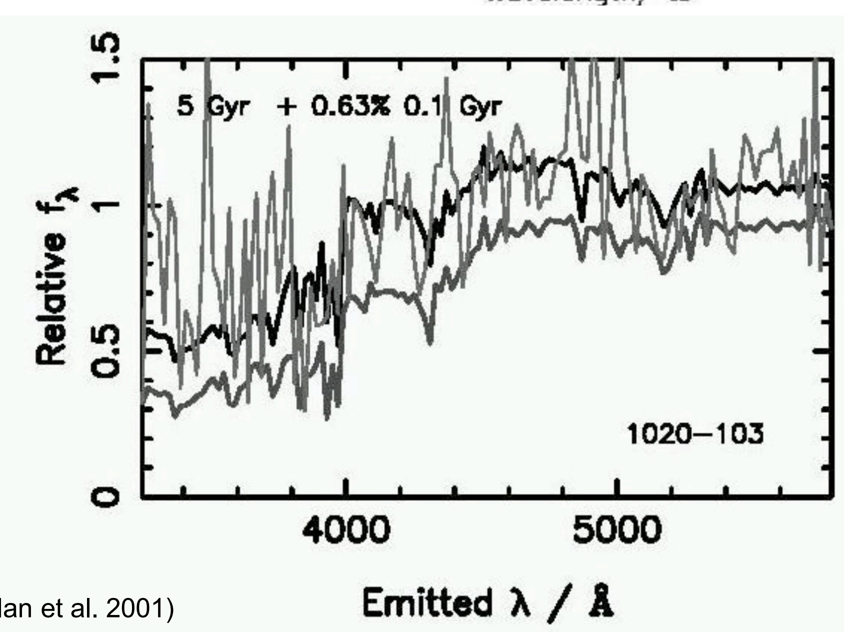
# QSO hosts at low-z: relics of past star formation?

Off-nuclear spectroscopy (Hughes et al. 2000, as per Boronson et al. 1985) of 26 AGN at $0.1 \leq z \leq 0.3$ shows the stellar features of an 8−12 Gyr population, but it may include a small (0−2% *M*) post-starburst contamination (Nolan et al. 2001). Because of the low S/N data, however, this result requires confirmation.




(Hughes et al. 2000)



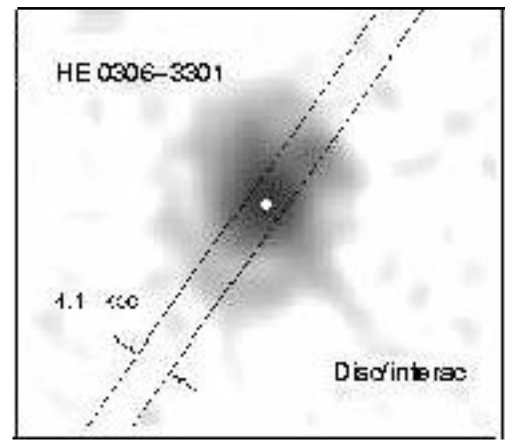

(Nolan et al. 2001)

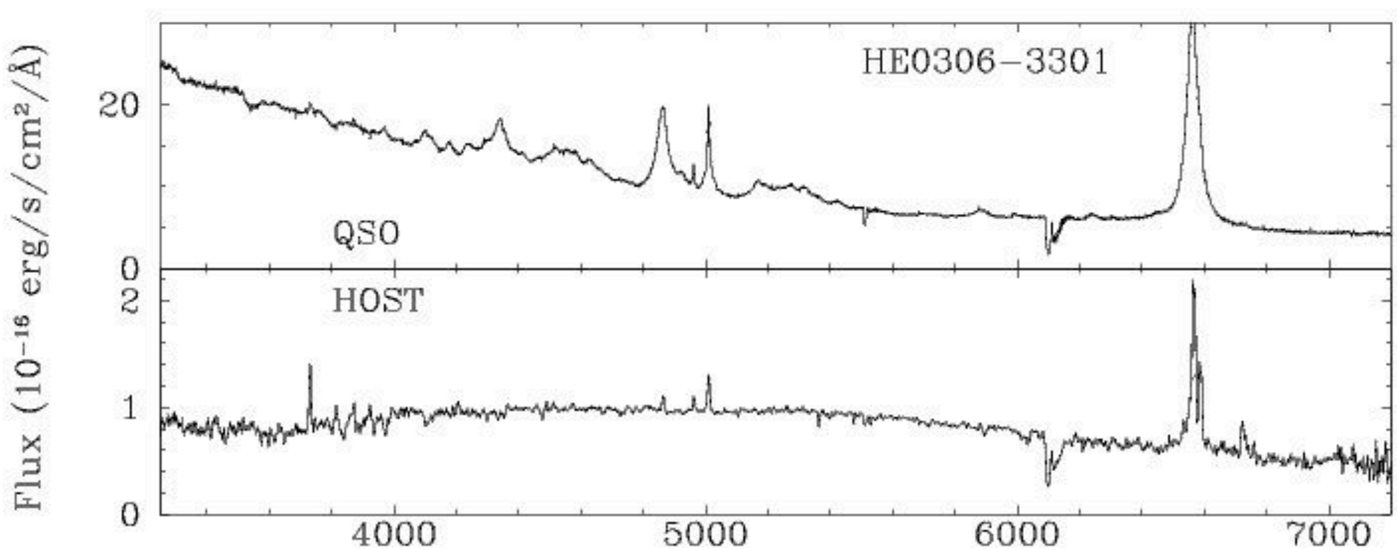
# QSO hosts at low-z: relics of past star formation?

On-nuclear spectroscopy with deconvolution of 20 RQ QSOs from the Hamburgh (slitless spectroscopy) QSO survey at z ≤ 0.3 shows (Lewave et al. 2007)

- 66% stellar populations of young Sc-type gals and large reservoirs of gas.
- 50% RQ QSOs in disk-like galaxies, but the most luminous are indeed E gals.
- 75% of E hosts have ionized gas and 50% signs of interactions
- only 15% of S hosts show signs of interactions.

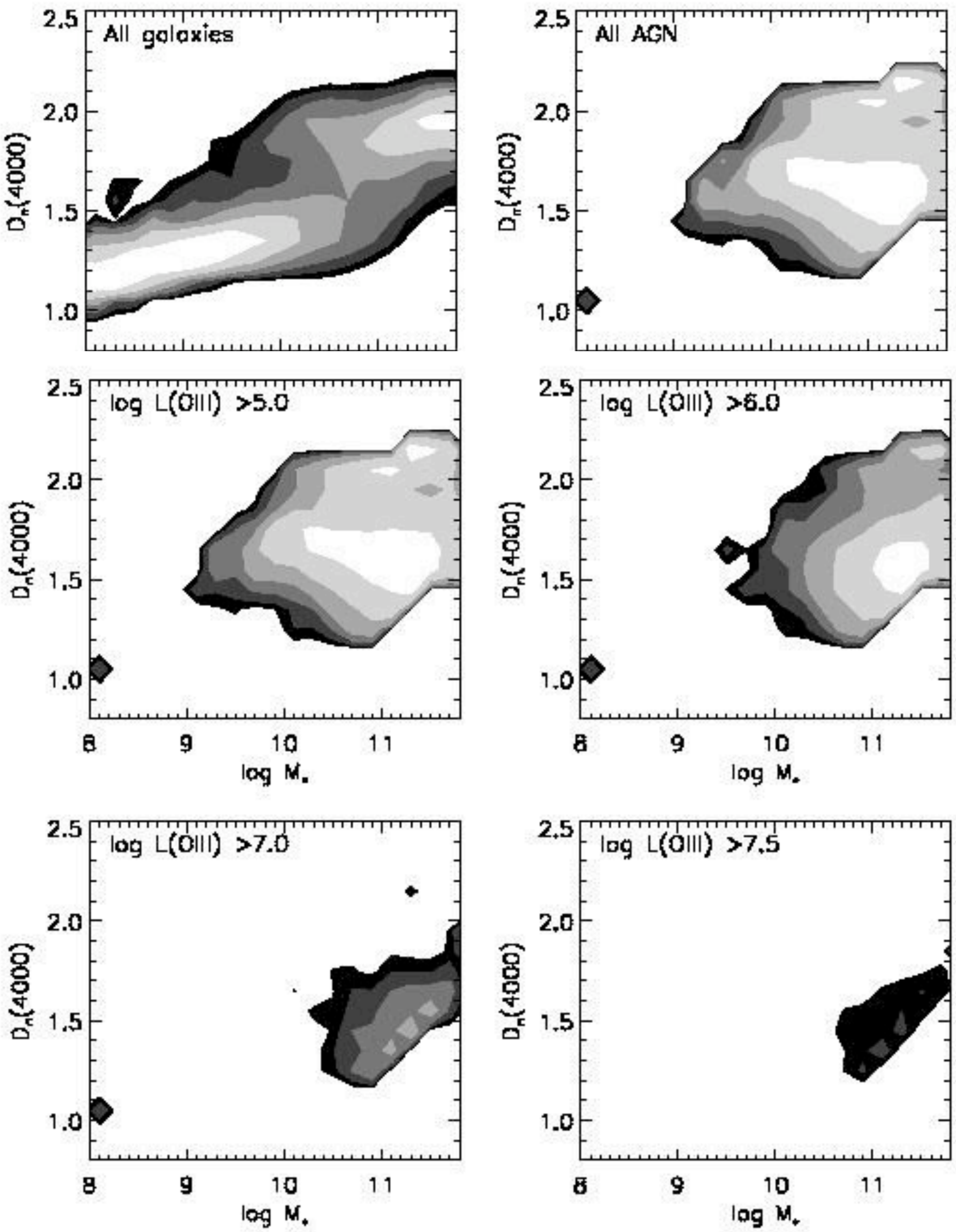
FIR properties of QSOs also indicate SF (Barthel 2006)




(Lewave et al. 2007)

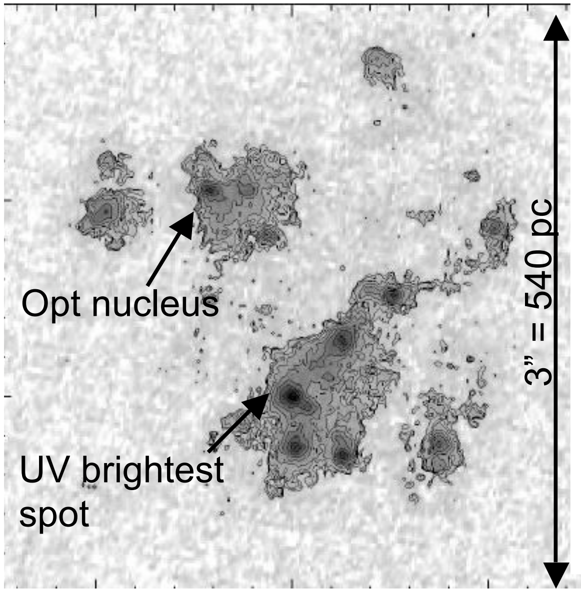
# AGN hosts at low-z: relics of past star formation?




The spectra of 26000 SLOAN narrow-line AGN show that they preferentialy reside in giant galaxies with signs of recent star formation, as revealed by the λ4000Å break measurements ($D_n$ index). The more active the galaxy is (as measured by the [O III] λ5007Å flux), the more massive and young the associated stellar population seems to be (Heckman 2003).

But are these young populations associated with the nucleus or with the host galaxy? — Fiber Φ=3”

# Stars in type-2 AGN: OB stars in Sy 2s




HST UV imaging and spectroscopy of 4 Sy 2s selected for being strong [O III] and 1.4GHz emitters (i.e. AGN properties) show resolved knots that are dominated by starburst features (Heckman et al. 1997, González-Delgado et al. 1998), with characteristic:

$L_{SB} \approx 10^{10} - 10^{11}\ L_{\odot}$

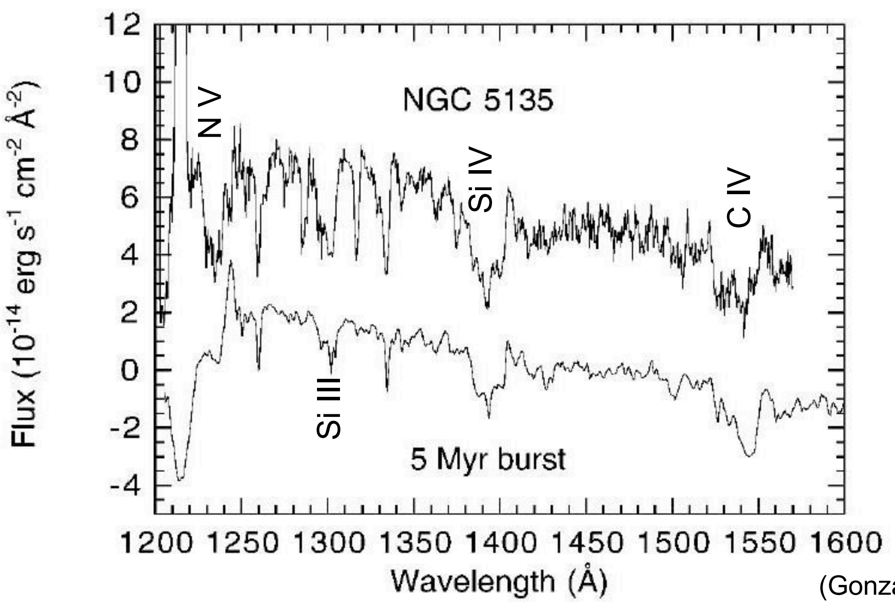
$M_{SB} \approx 5 \times 10^{6} - 5 \times 10^{7}\ M_{\odot}$

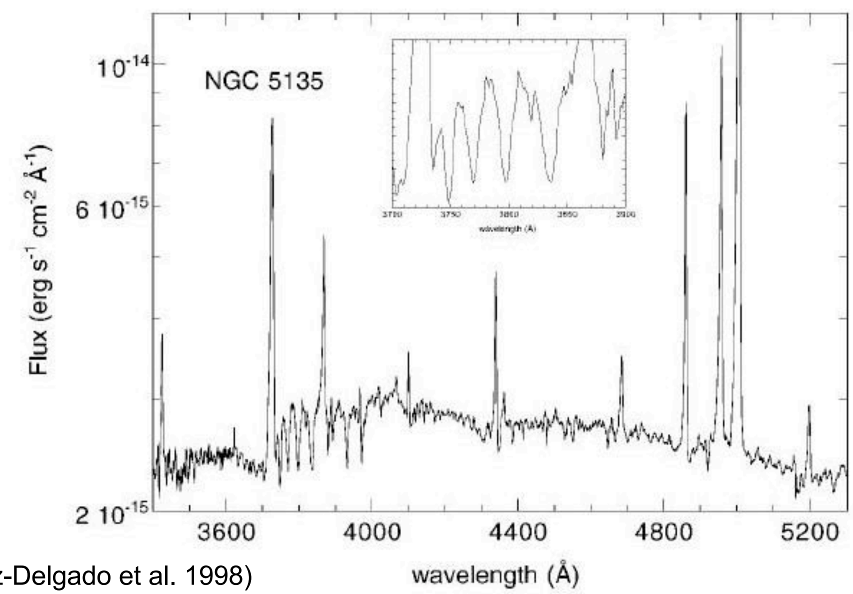
age ≈ 3 − 6 Myr

$Z \geq Z_{\odot}$

size ≈ 100 pc

as luminous as the hidden nucleus, which can be inferred from the N V emission lines.




(González-Delgado et al. 1998)

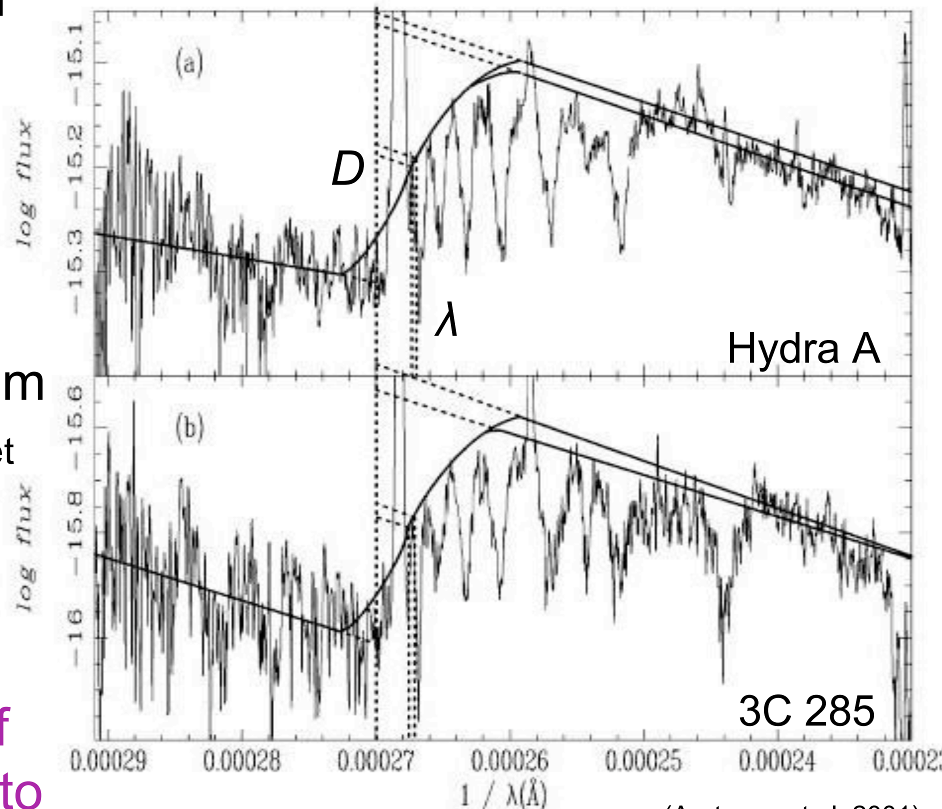
# Stars in type-2 AGN: young populations

Early indications of massive starbursts in nuclear regions of AGN through CaT (Terlevich et al. 1993), CO EW (Oliva et al. 1995).

50% Sy 2 show absorption lines characteristic of starburst to post-starburst ages, 5 Myr − 1 Gyr, that completely account for all the continuum emission (Schmitt et al. 1999, González-Delgado et al. 2001, Cid-Fernandes et al. 2001)

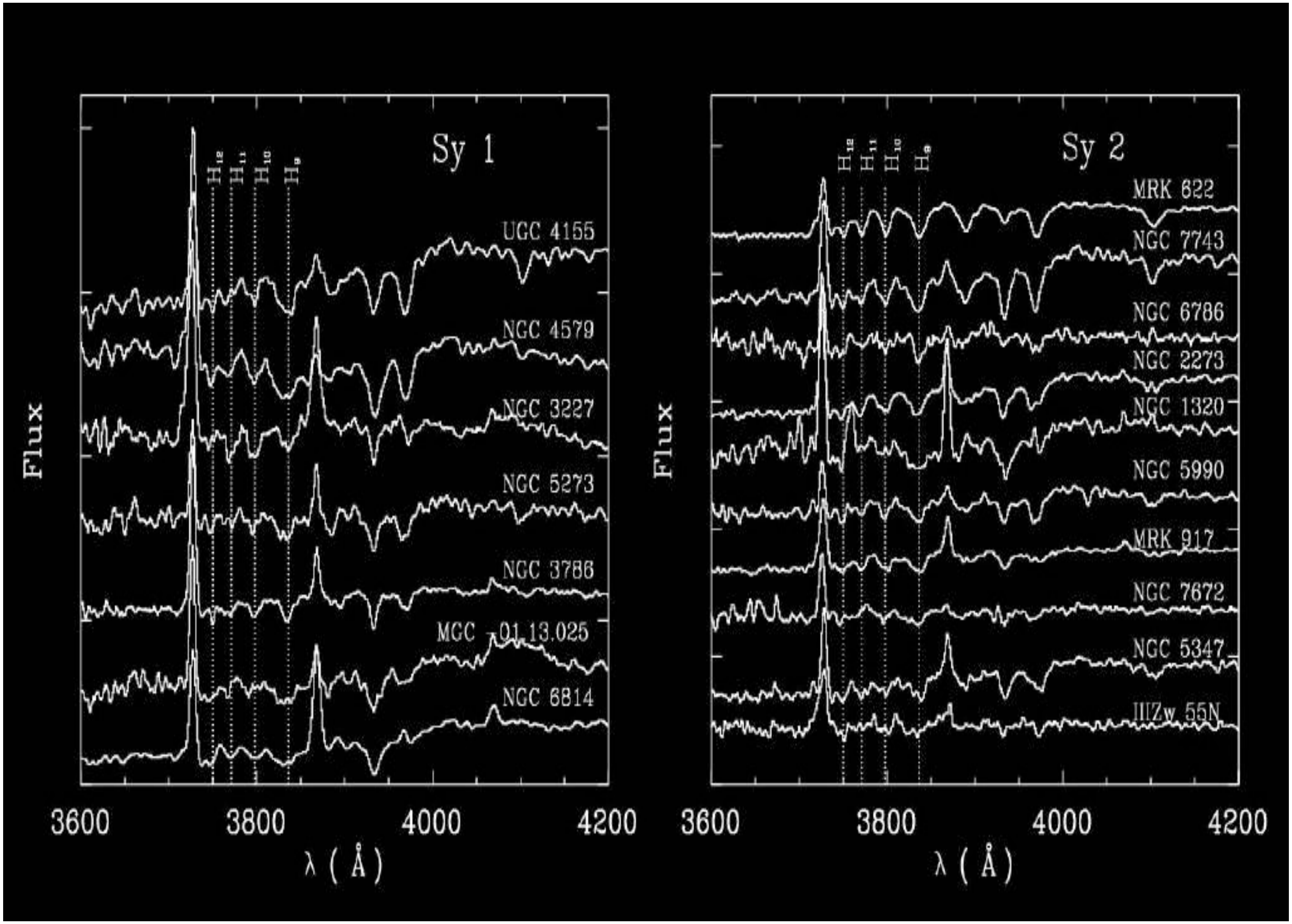
30% NLRGs have prominent nuclear SBs, 7-40 Myr old (Aretxaga et al. 2001, Willis et al. 2002, Tadhunter et al. 2002)

The SBs can also solve the problem of the second continuum source needed to explain the low polarization levels of the continuum of Sy 2s (Tran 1995, Cid Fernandes & Terlevich 1995). Big Blue Bump of these might be purely stellar!




(Aretxaga et al. 2001)

# Stars in type-1 AGN: young populations

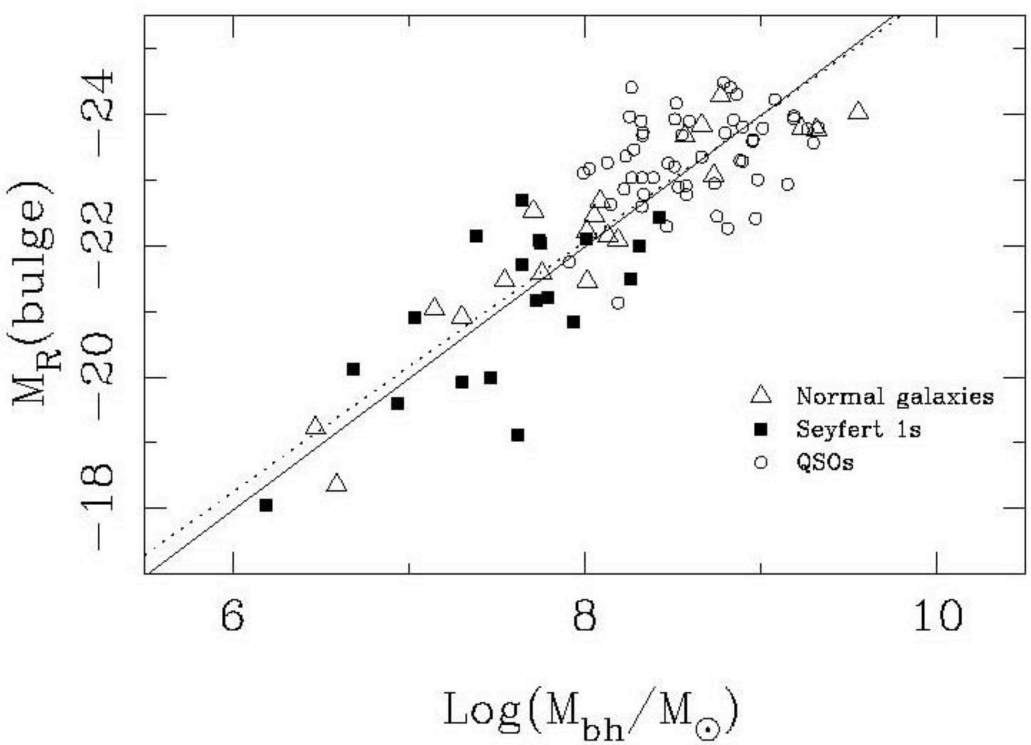


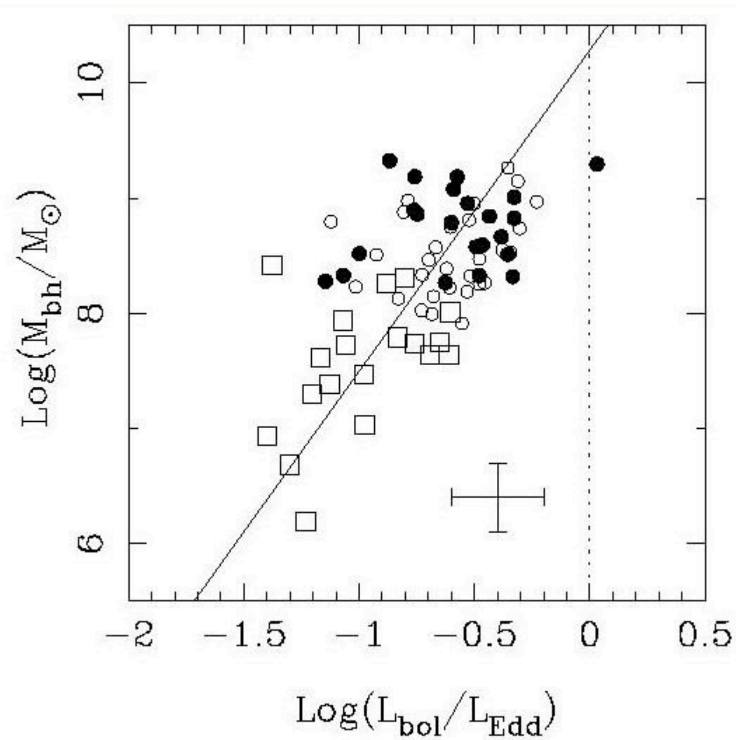

Torres-Papaqui (2005)

# Low-*z* QSOs: BH-spheroid relation

The BH-bulge relationship found in nearby galaxies is shared by the AGN where good determinations of the BH mass are available either by reverberation (e.g. NGC 5548) or by rotational curves (e.g. NGC 4258). In a sample of 30 QSOs at $0.1 < z < 0.3$, 19 Seyferts, and 18 inactive S galaxies with reliable bulge luminosities, and applying a M/L relationship, it is found that the masses of BH and bulges are linked by $\boxed{M_{\rm BH} \propto M_{\rm bulge}^{(0.95\pm0.05)}}$

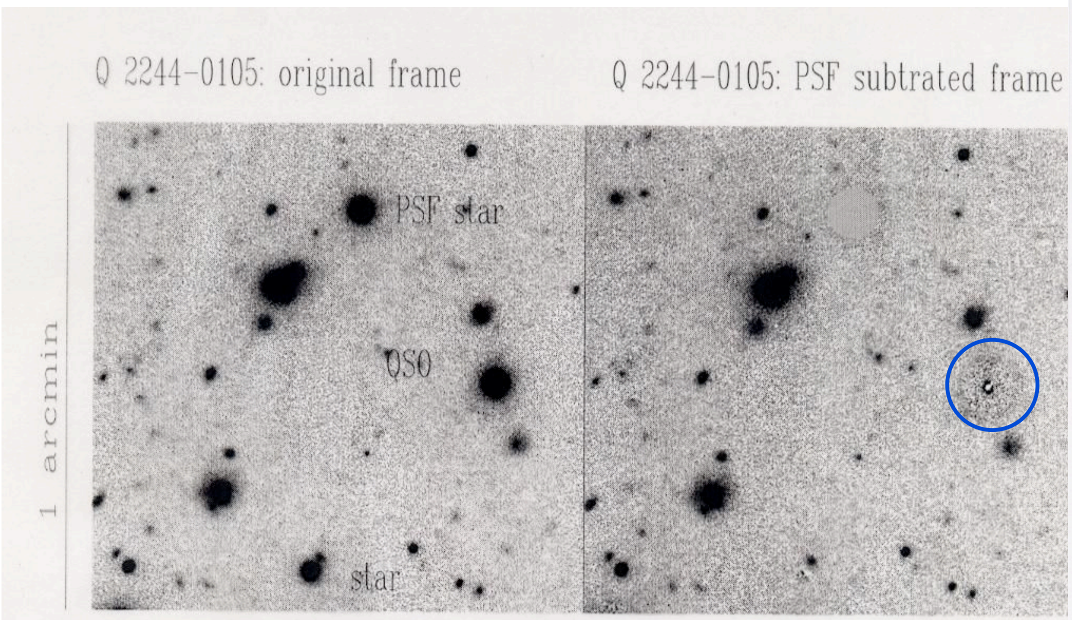
The QSO BHs are radiating at ≤10% of the Eddington limit (McLure & Dunlop 2001)



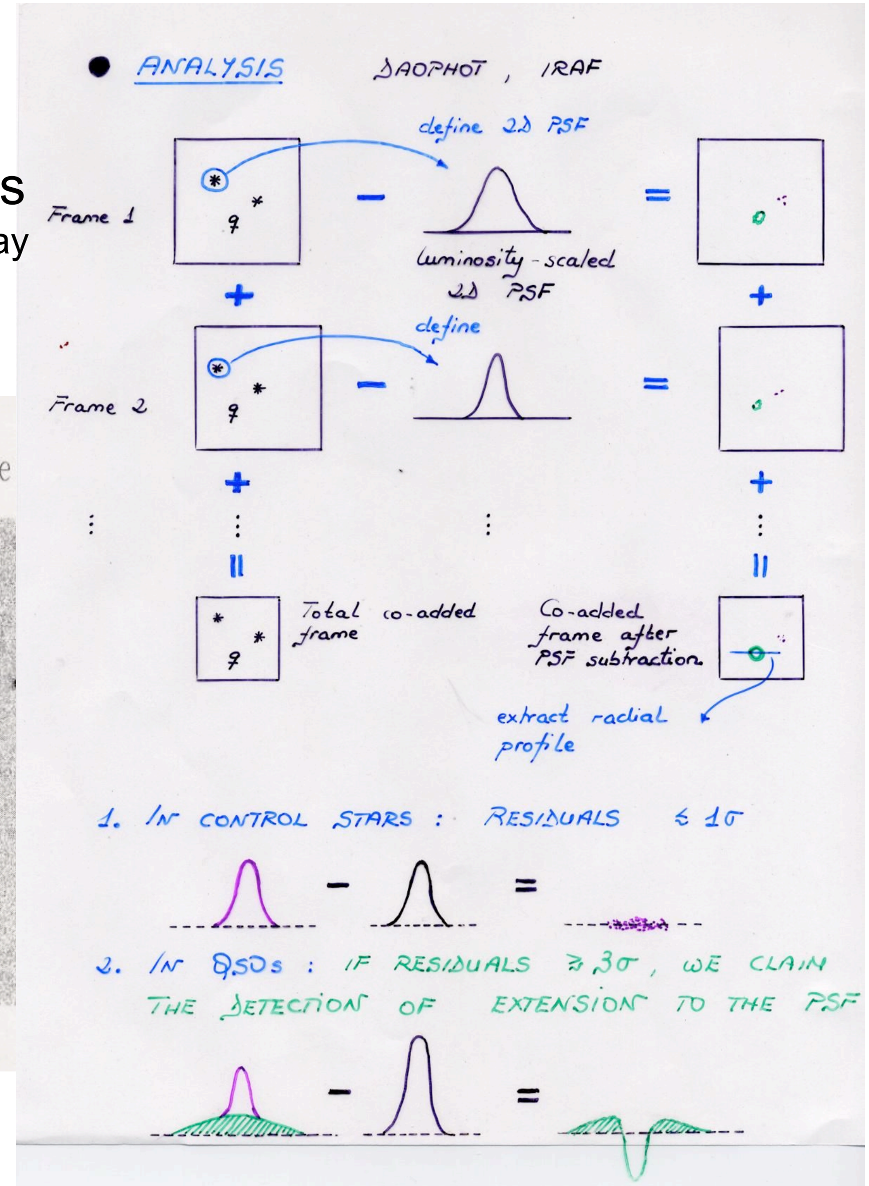



# QSO hosts at high-z: giant blue galaxies?

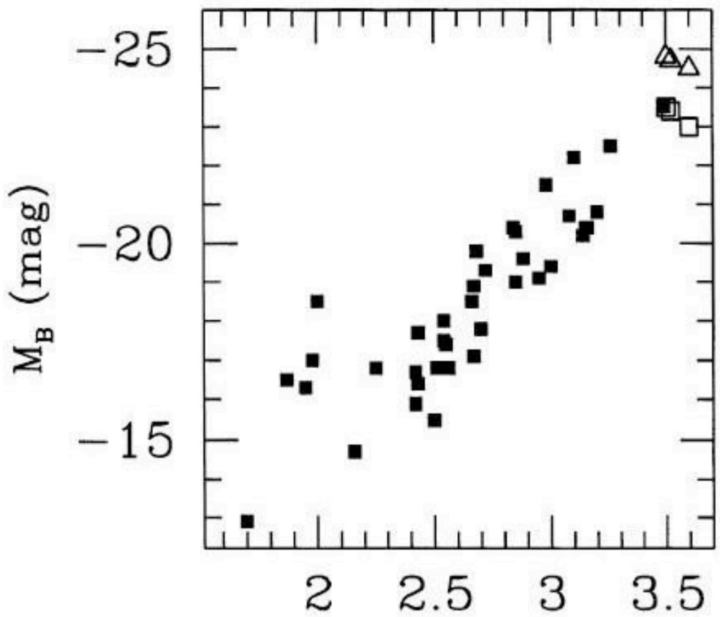
The host galaxies of z≈2−3 RL and RQ QSOs have been detected at observer-frame optical and NIR bands, which correspond to UV−optical rest-frame bands (e.g. Lehnert et al. 1992, Aretxaga et al. 1995, 1998, Ridgway et al. 2001, Falomo et al. 2005, Kotilainen et al. 2007).



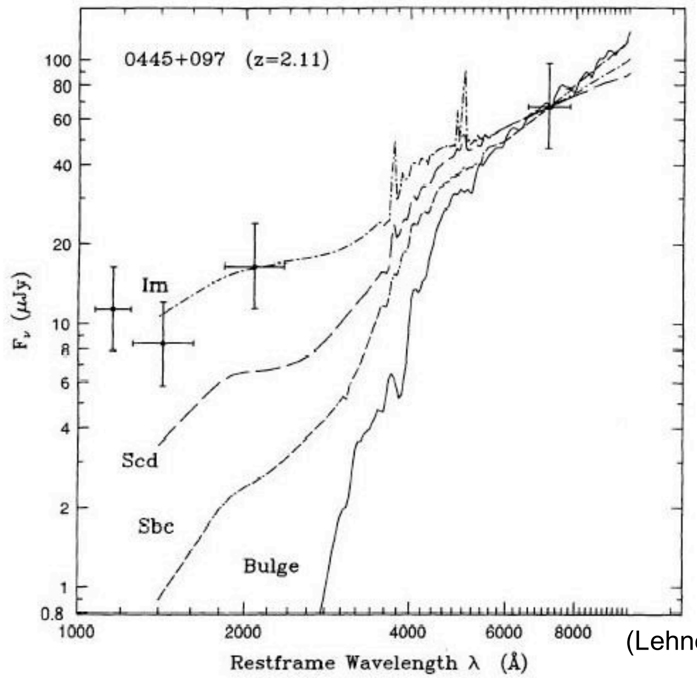

(Aretxaga et al. 1995)



# QSO hosts at high-$z$: giant blue galaxies?




(Aretxaga et al. 1998)

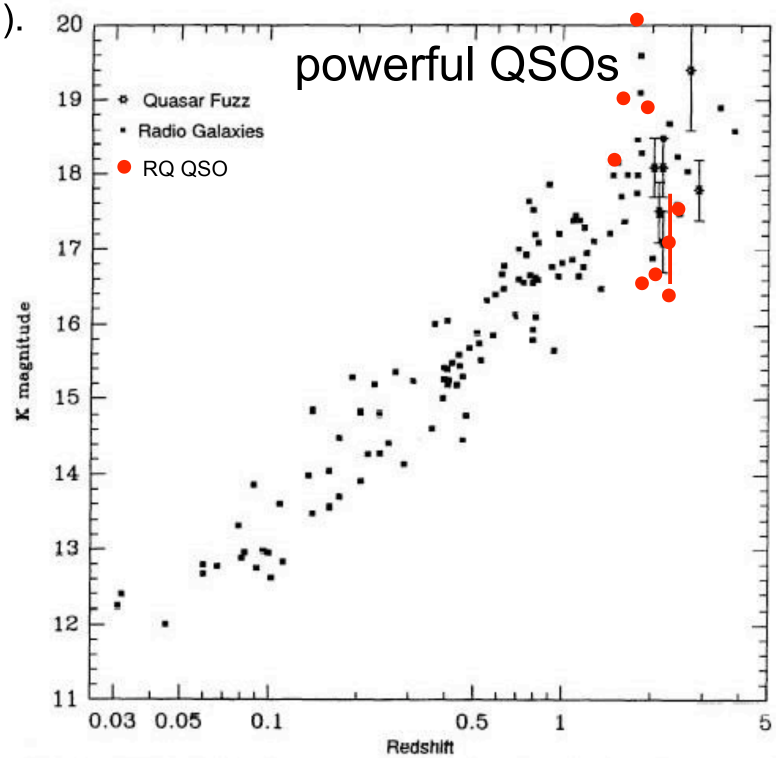



(Lehnert et al. 1992)

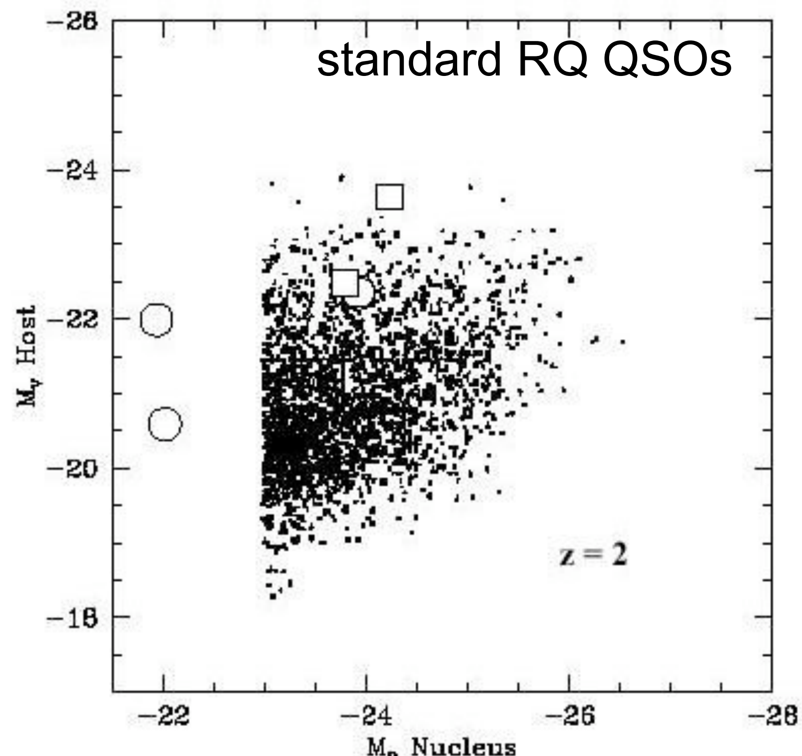
The hosts of luminous $z$=2−2.5 QSOs are big (FWHM=1 arcsec ≈ 4 kpc for RQs) and UV bright: $L_{host}$=5−12% $L_{QSO}$ for RQ to RL QSOs, respectively (Lehnert et al. 1992, Aretxaga et al. 1998, Schramm et al. 2007), but the samples are small. The light is probably not scattered from the nucleus, since the colours are redder than the nuclear light. The SED of one of the RL QSOs, which has been detected in 4 pass-bands, looks like that of a Magellanic irregular. The UV light implies SFR > 200 $M_\odot$/ yr, so we probably are witnessing the formation of the spheroid.

# QSO hosts at high-z: the building of spheroids

K-band imaging reveals that powerful z≈2–3 RL QSOs (sample of 6, Lehnert et al. 1992) and RQ QSOs (sample of 6, Aretxaga et al. 1998, Falomo et al. 2005, Kuhlbrodt et al. 2005, Kotilainen et al. 2007) follow the same magnitude-relationship as first-rank cluster members. The luminosities are above $3L_*$. These probably become luminous E galaxies. Typical RQ QSOs (sample of 5) seem to be $L_*$ galaxies with a range 0.2−4 $L_*$ (Ridgway et al. 2001). Its nuclear-to-host luminosity is reproduced by semi-analytical galaxy+BH formation scenarios (Ridgway et al. 2001).



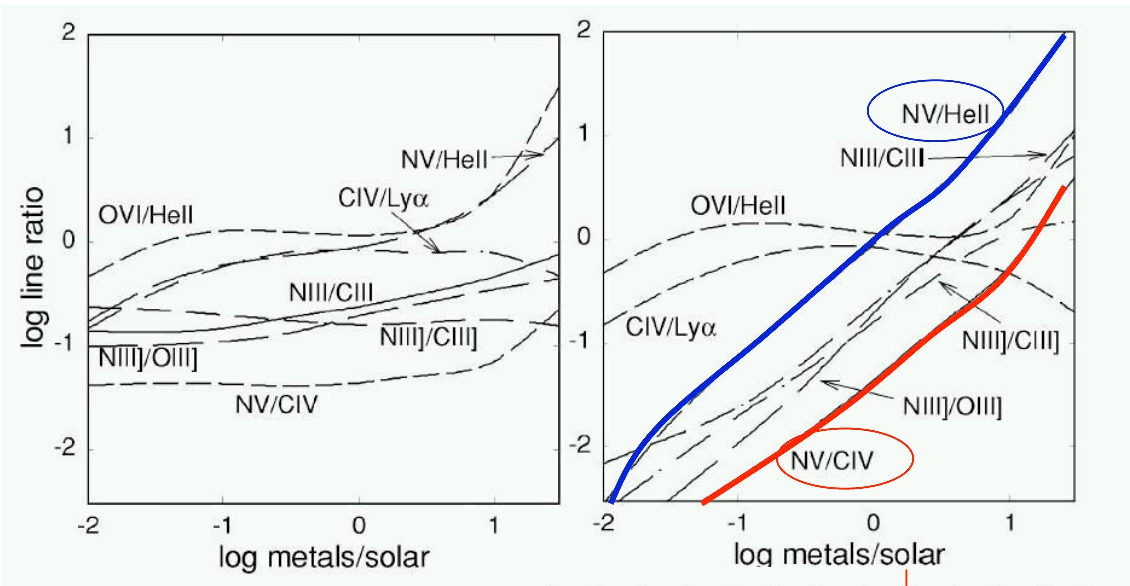

(Lehenrt et al. 1992, Aretxaga et al. 1998)



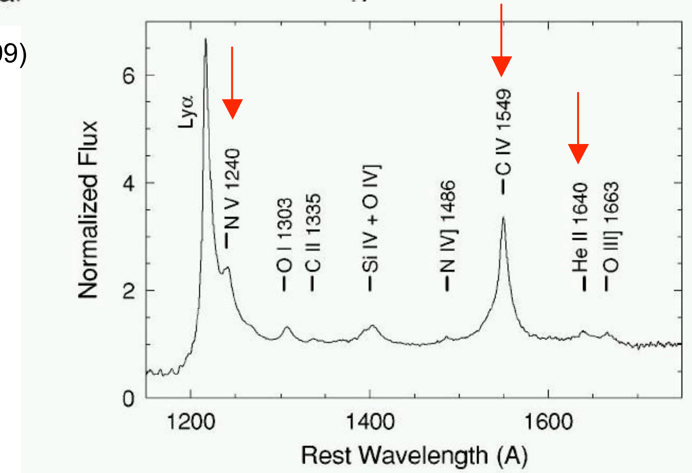

(Ridgway et al. 2001, comparison with Kauffman & Haehnelt 2000)

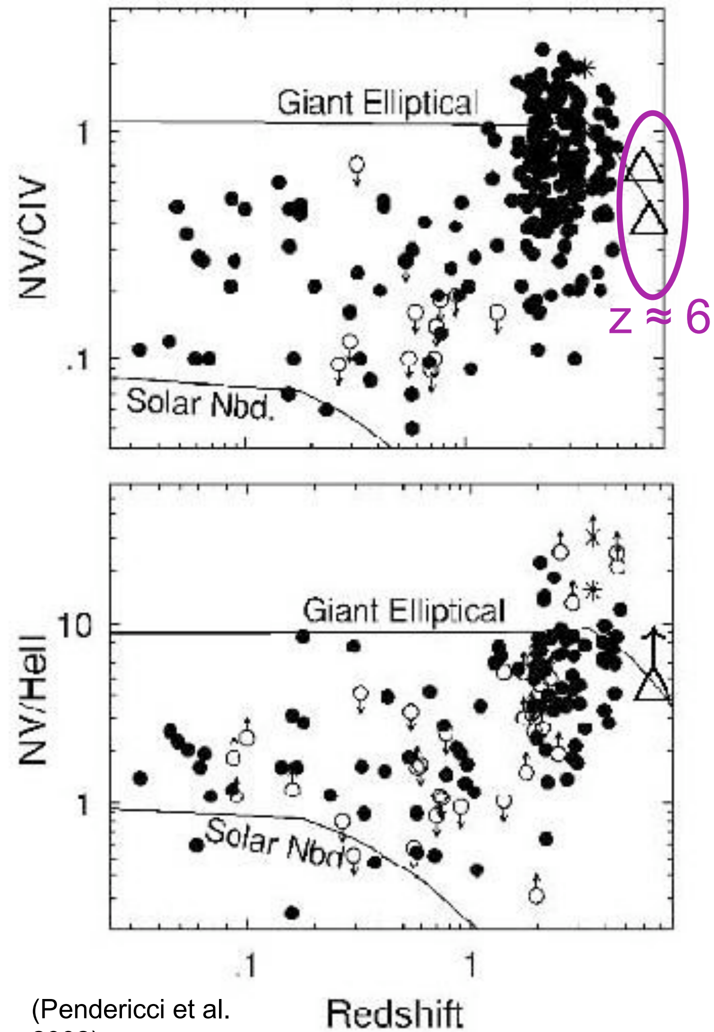
# QSO hosts at high-z: the building of spheroids

Photoionization modeling of the BLR in high-z QSOs implies that the metallicities of the gas orbiting the engine are typically oversolar (Hamann & Ferland 1993, …,1999), and this picture extends up to the z≈6 (Pendericci et al. 2002).




(Hamann & Ferland 1999)

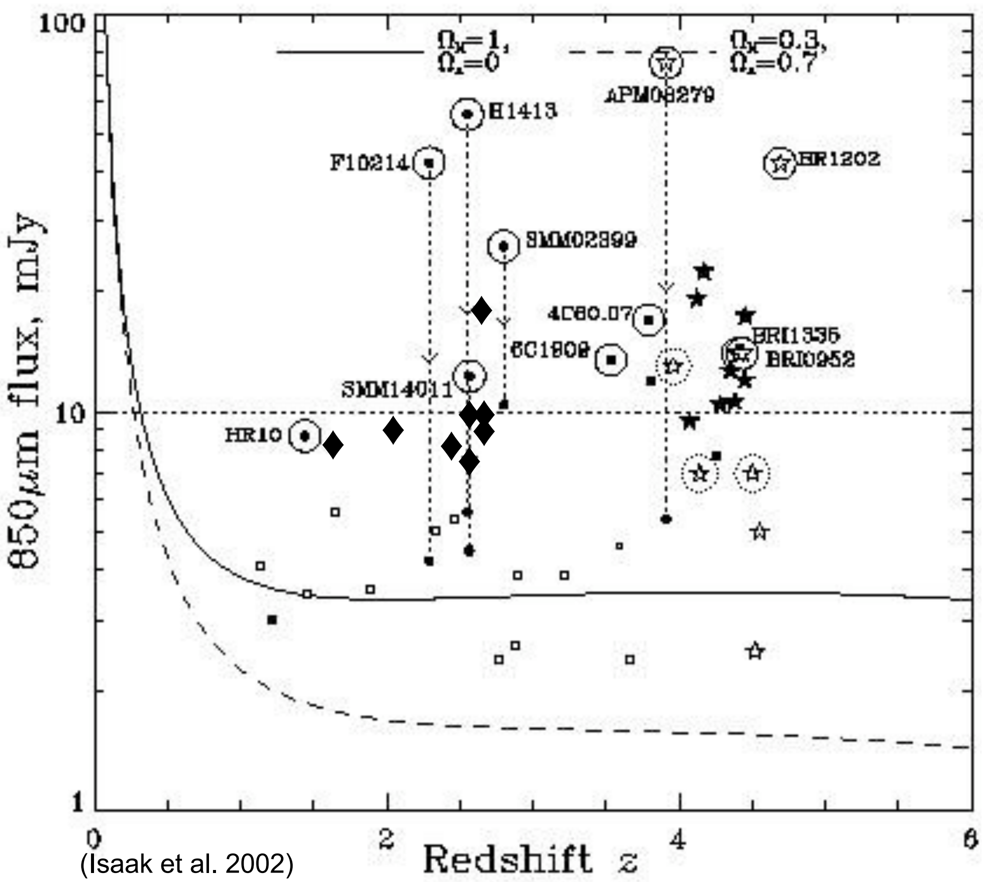


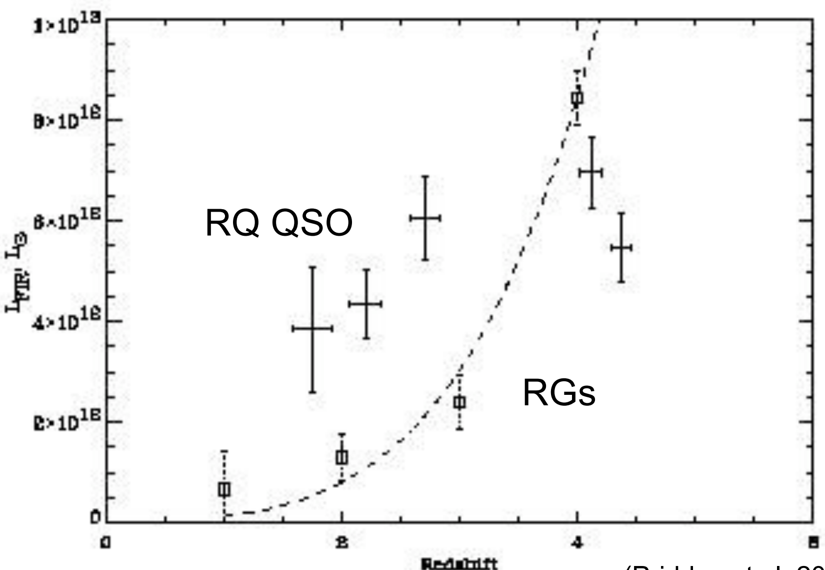

(Pendericci et al. 2002)

# QSO hosts at high-z: the building of spheroids

Intense sub-mm/mm thermal emission has been detected in high-z AGN, implying large masses of dust are present early on (Isaak et al.1994, McMahon et al.1994) The FIR luminosities of typical RQ QSOs are $L_{FIR}$=1.1–2.6 x $10^{13} L_\odot$ , which translates into dust masses of $M_D$=0.8–2.0x$10^8$ $M_\odot$ and SFR=1100–2600 $M_\odot$ yr $^{-1}$ (assuming all UV heating is due to star formation). No evolution is inferred for RQ QSOs (Priddey et al. 2003), but a strong $(1+z)^{3–4}$ evolution is inferred for RGs (Archibald et al. 2001). However, the selection criteria and survey depths are not matched.



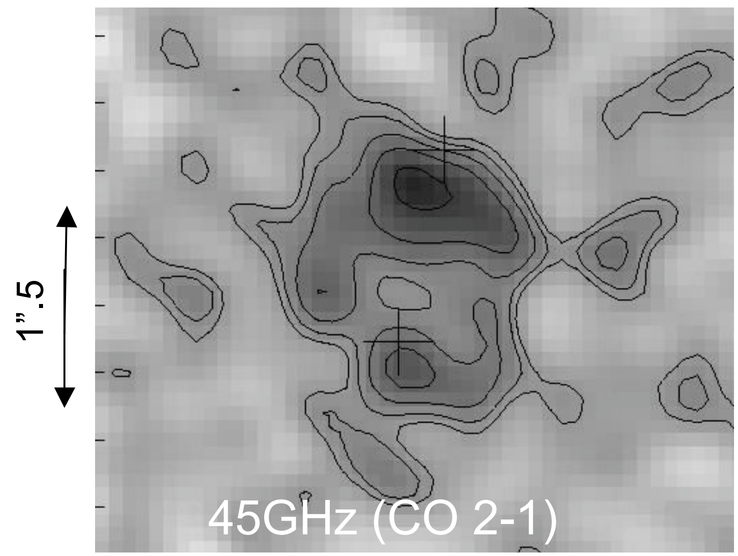

(Isaak et al. 2002)

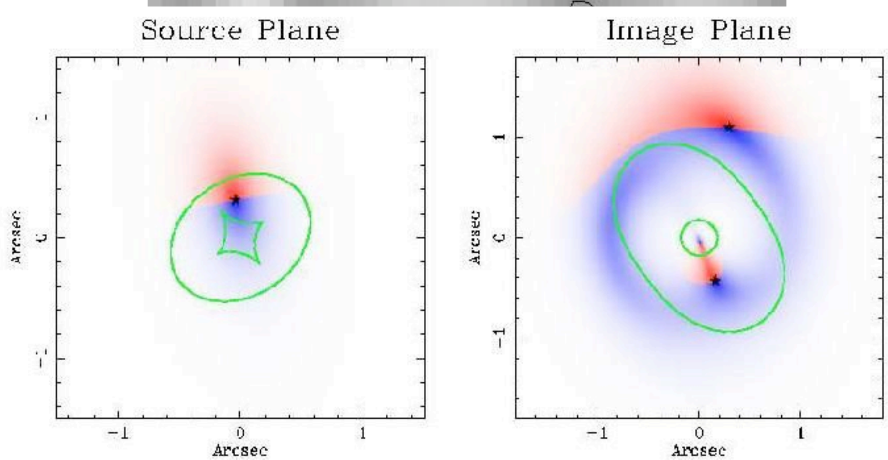


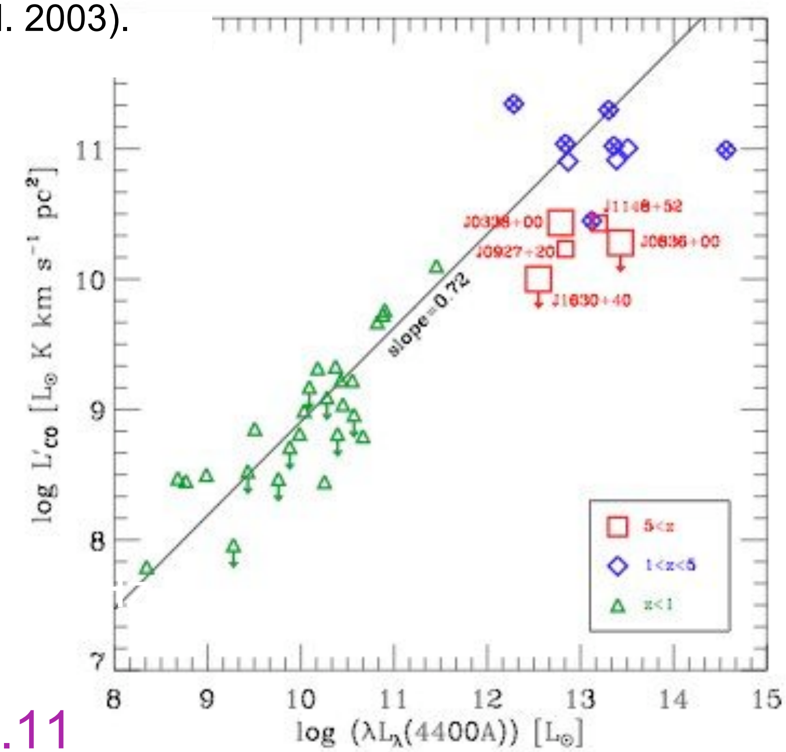

(Priddey et al. 2003)

# QSO hosts at high-*z*: the building of spheroids

Follow-up CO interferometry of the dusty QSOs imply that they contain large reservois of molecular gas $M \geq 10^{10}\, M_{\odot}$ at $z \approx 4$ (Omont et al. 2001). This emission has been resolved in a high-*z* QSO (Carilli et al. 2003).



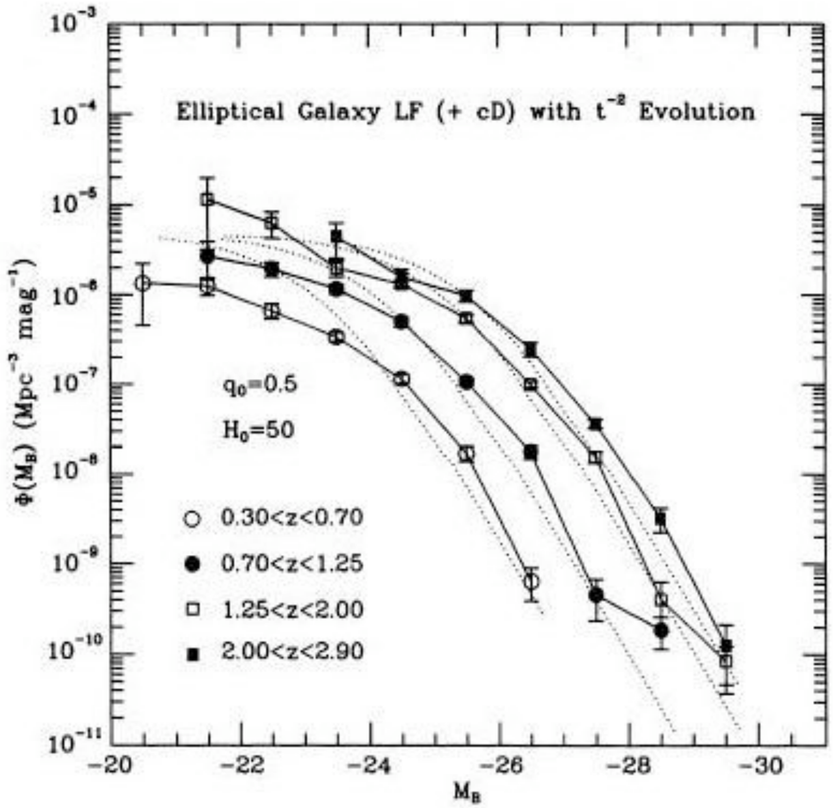

(Maiolino et al. 2007)

$z = 4.11$
$M_{gas} = 2 \times 10^{11}\, M_{\odot}$
$r \approx 2$ kpc
SFR $\approx 900\, M_{\odot}$/yr

(Carilli et al. 2003)

# *Heretical* models for QSOs: galaxy formation

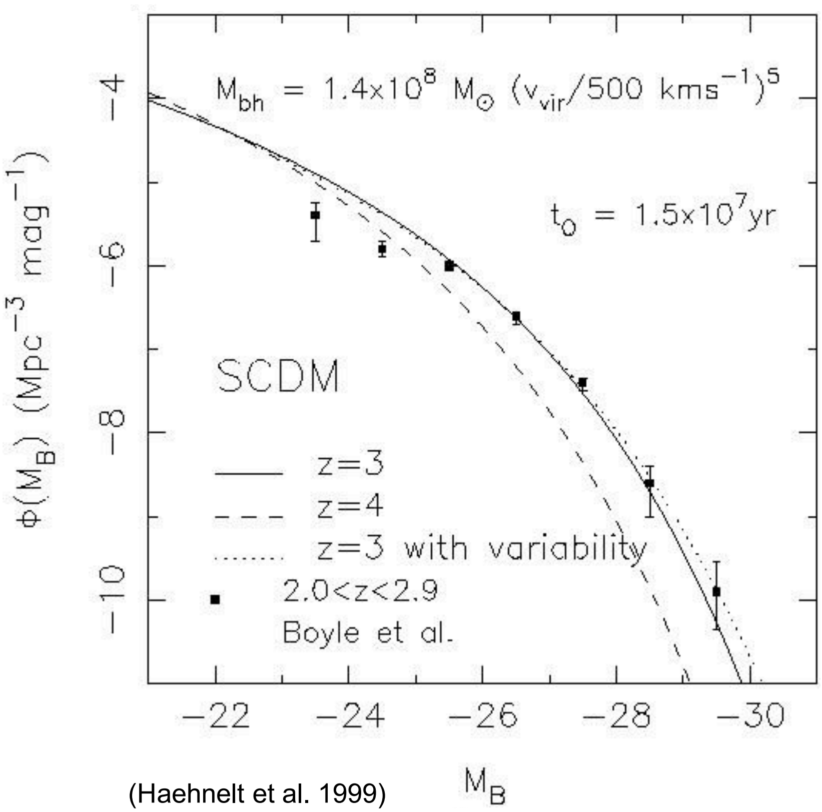
Pure SB models that try to explain the optical-UV properties of QSOs only make sense if they are, in some way, linked to the building of big spheroids, because of the huge masses required for the SBs.
A model requiring the participation of 5% of an E galaxy in a SB, from monolithic collapse approximations for galaxy formation, can reproduce the luminosities and LF evolution of QSOs (Terlevich & Boyle 1993).



# The AGN role in galaxy evolution

The shape of the density evolution of UV light emitted by QSOs also has a similar shape to the density evolution of UV light emitted by field galaxies detected in deep surveys (Boyle & Terlevich 1998).

The LF evolution has also been reproduced by models of the growth of BHs and galaxies within the Press-Schechter formalism (Haehnelt et al. 1993, 1999).



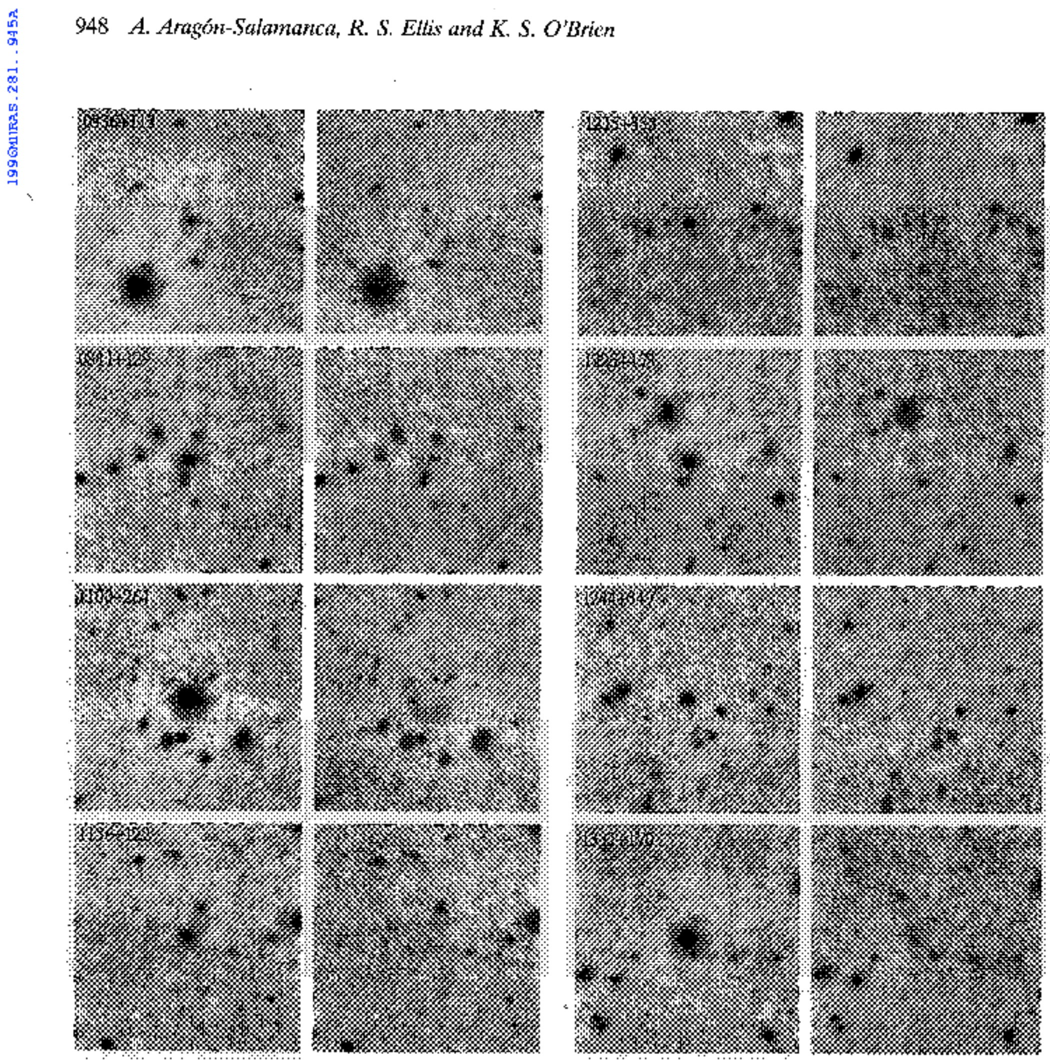

(Haehnelt et al. 1999)

The Press-Schechter formalism is used to obtain the halo mass function $\Phi(M_{halo})$ at any given epoch. This can be related to the BH mass via a BH-halo mass relationship (a la BH-bulge). Assuming a time evolution of the QSO $L(t) = L_E \exp(-t/\tau_Q)$ the LF at $z$<3 can be reproduced for a range of QSO life-times:

$\tau_Q = 10^6$ yr with $M_\bullet \alpha\, M_{halo}^{5/3}$ to $\tau_Q = 10^8$ yr with $M_\bullet \alpha\, M_{halo}$. However, one needs to assume $M_\bullet/M_{halo}\ \alpha\ (1+z)^{5/2}$ or that the mass accretion falls by a factor of 100 (Haehnelt et al. 1999).

# QSO environments

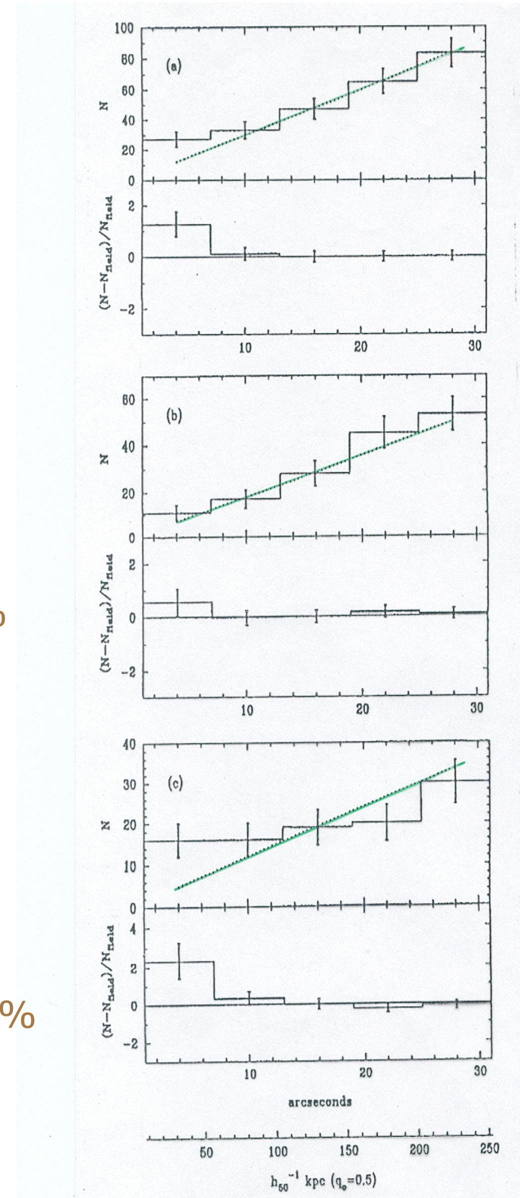
RL QSOs show an excess of companion galaxies over blank-fields, RQ QSOs do not (Aragón-Salamanca et al. 1996, Teplitz et al. 1999).




QSOs: 85%

RQ QSOs: 39%

RL QSOs: 99.5%



# Mapping high-z overdensities

• We are searching for luminous mm galaxies in high-*z* Universe to trace the distribution of massive elliptical galaxies and the mass assembly in proto-clusters

$z$~3, $SFR_{const} \sim M_E/t_{age} \approx 3\times10^{12} / 2\times10^9 \approx 1500\ M_\odot/yr$

$\rightarrow > 6\times10^{12}\ L_\odot$ (FIR) or $S_{1.1mm}$~3 mJy

• powerful AGN reside in massive elliptical galaxies and at high-*z* have been shown to be surrounded by companion galaxies that could be identified with proto-clusters. Thus we can measure

- number-density of (sub-)mm galaxies - SMGs
- spatial distribution
- luminosities, SFRs & masses

We can demonstrate that massive (elliptical) galaxies form rapidly in proto-clusters at the biased high-density peaks in the underlying dark matter distribution . This is a tracer to test DM model predictions of large-scale structure (i.e. cluster) formation in the high-z universe

letters to nature

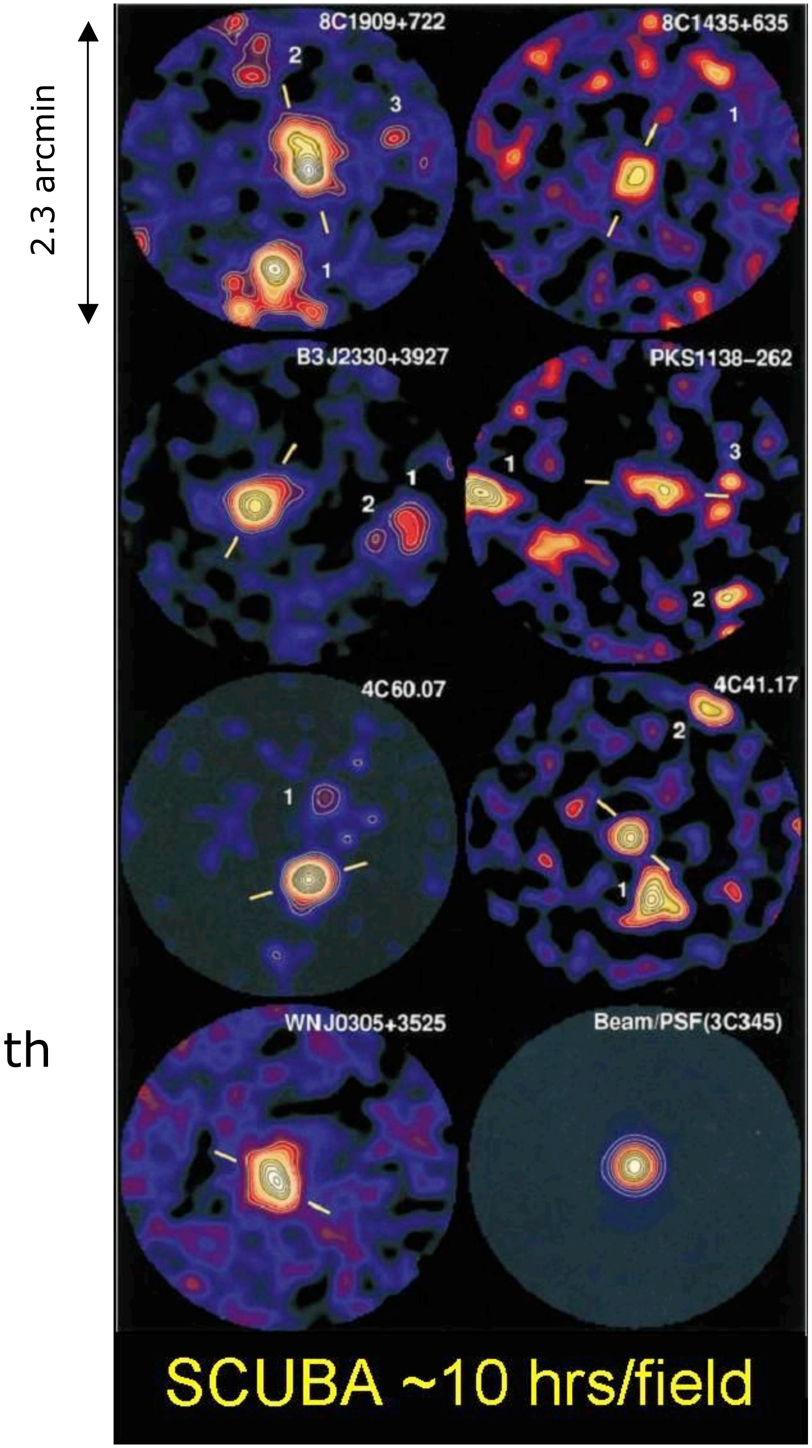
## The formation of cluster elliptical galaxies as revealed by extensive star formation

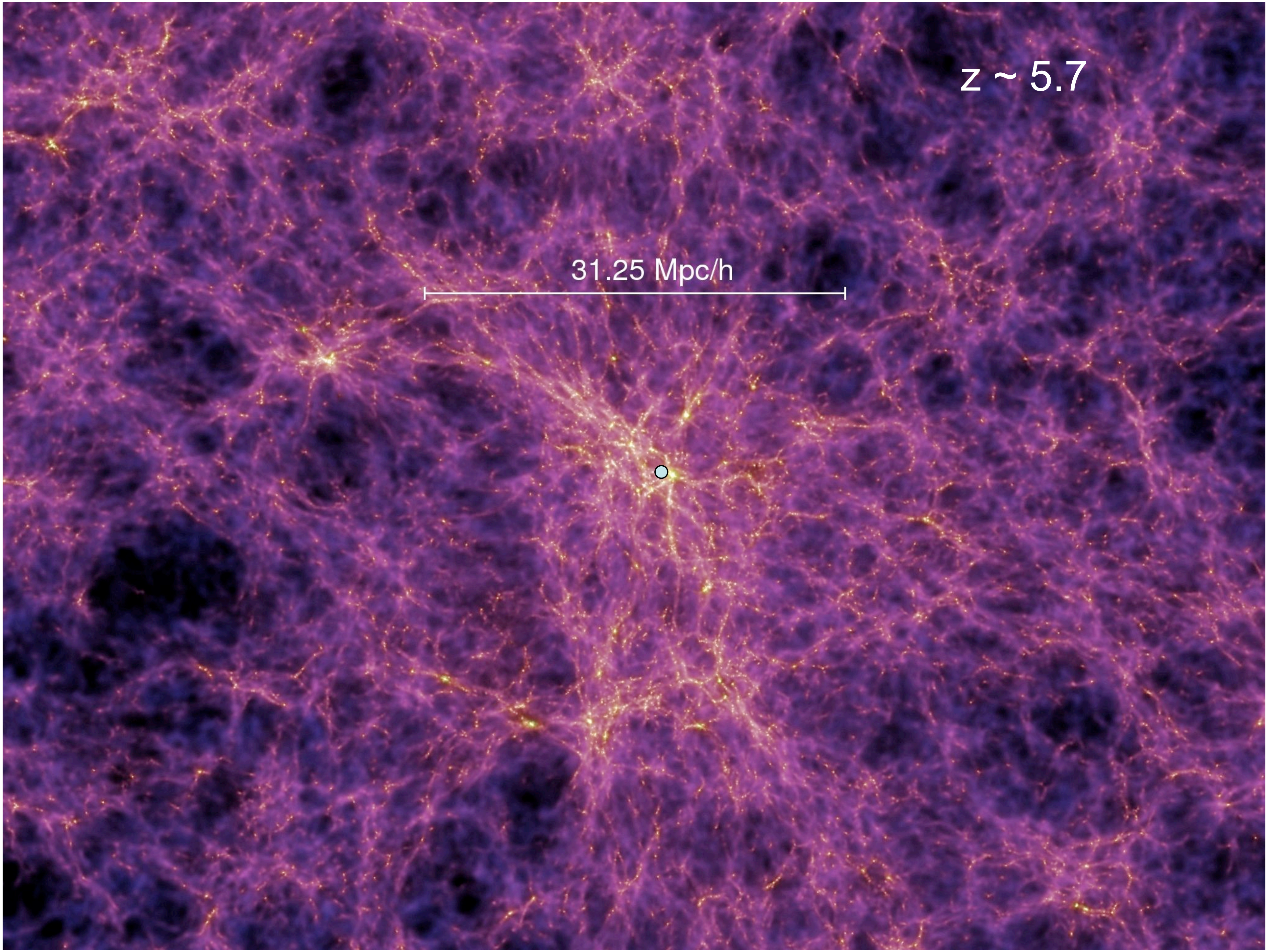
J. A. Stevens[1], R. J. Ivison[1], J. S. Dunlop[2], Ian R. Smail[3], W. J. Percival[2], D. H. Hughes[4], H. J. A. Röttgering[5], W. J. M. van Breugel[6] & M. Reuland[6]

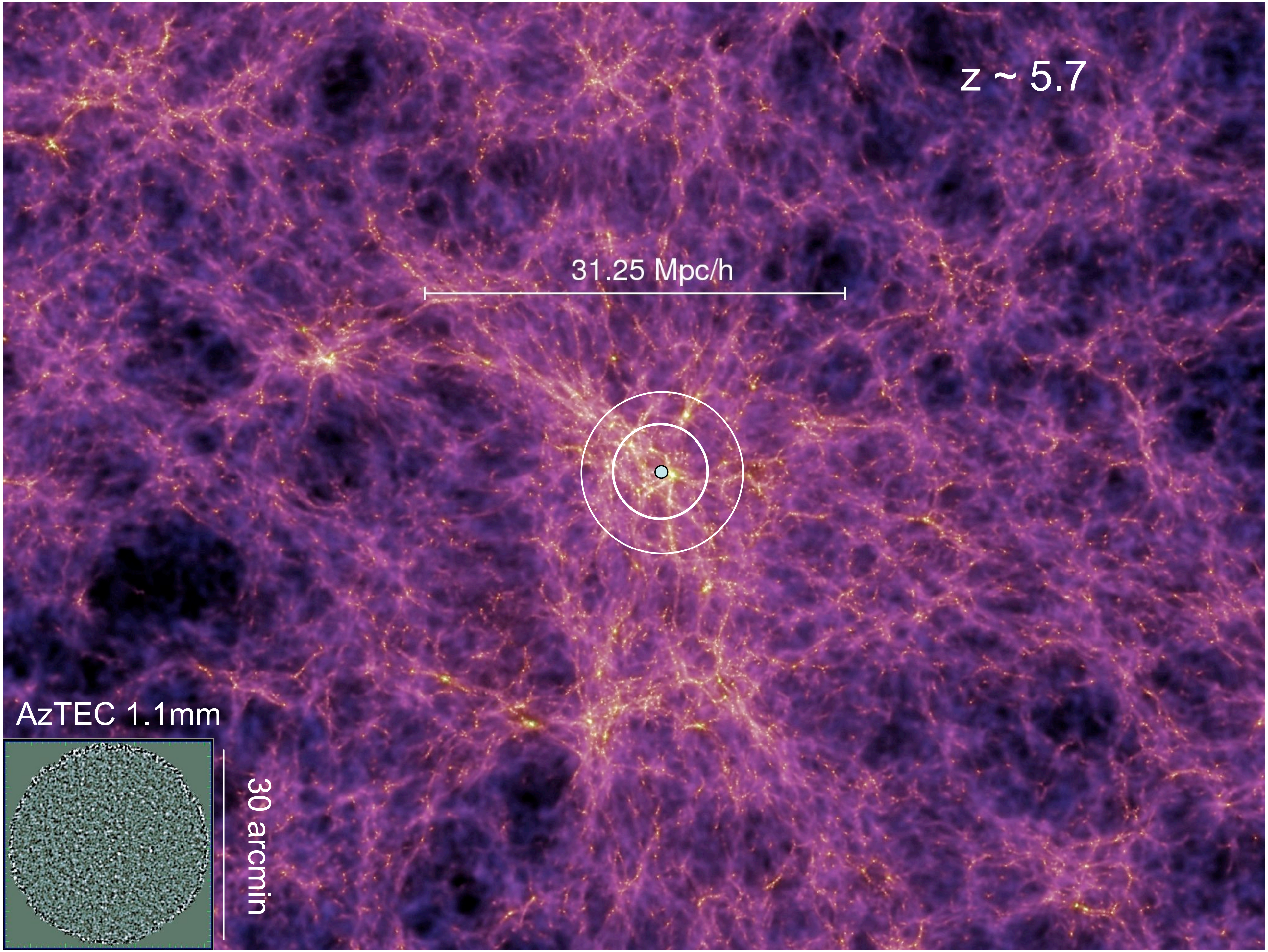
2003, Nature, 425, 264

SCUBA 850μm imaging (~6 sq. arcmins) of powerful AGN at $2.2 < z < 4.3$

- achieved $1\sigma \sim 1 - 2$ mJy at 850μm
- detected over-density (factor of a few)
- evidence for alignment of over-density with central AGN radio-jet axis




z ~ 5.7
31.25 Mpc/h


z ~ 5.7
31.25 Mpc/h
AzTEC 1.1mm
30 arcmin

(Some unpublished results have been erased here)

# Active Galactic Nuclei

Itziar Aretxaga (INAOE), 2007

Bibliography: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- “Advanced Lectures on the Starburst−AGN Connection”, 2001, Eds. I. Aretxaga, D. Kunth & R. Mújica, Word Scientific.
  With reviews by B.P. Peterson, R. Goodrich, H. Netzer, S. Collin, F. Combes, R.J. Terlevich & B.J. Boyle.
- A compilation of useful reviews can be found in Level 5 @ IPAC, and the rest of the references can be found in papers listed in ADS or astro-ph


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