Cosmic Evolution of Quasar Hosts

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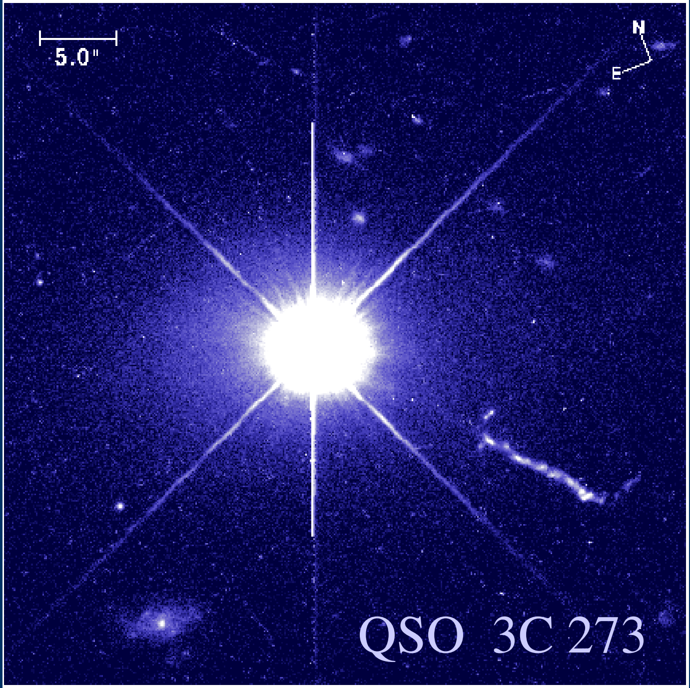
Santiago, 25 January 2006



- The QSO-host paradigm
- Properties of host galaxies of quasars at low z
- High z quasar hosts
- Results from VLT (+ AO) images of z > 1 quasars.
- The cosmic evolution of QSO hosts up to z = 3

The properties and quasar hosts at low and high redshift

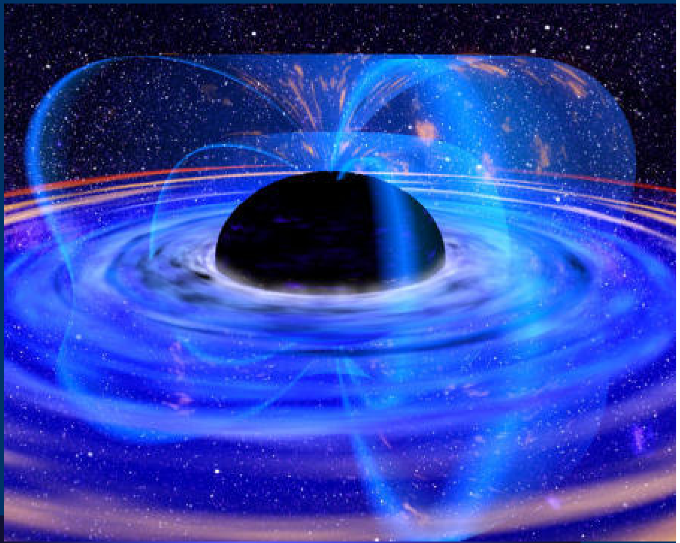
Credits: List of investigators

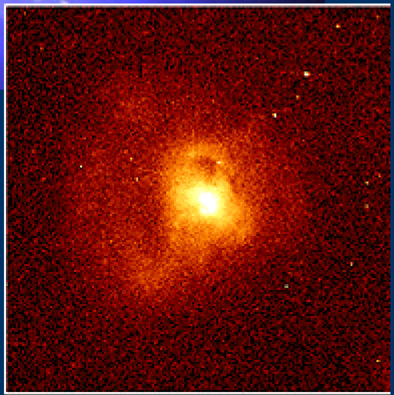
- R. Falomo (INAF – Padova, Italy)
- J. Kotilainen (Tuorla Obs, FIN)
- T. Hyvonen (Tuorla Obs, FIN)
- R. Scarpa (ESO, Chile)
- A. Treves (Univ. Insubria, Italy)
- M . Labita (Univ. Insubria, Italy)
- M. Uslenghi (INAF- Milano, Italy)

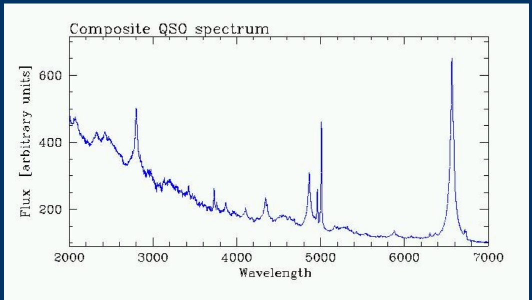
How to make a quasar

The ingredients:

- a supermassive BH
- fueling gas (accretion disk)
- BLR + NLR: surrounding gas (clouds)
- dust: obscuring material (complex geometry)
- the host galaxy
- the environments







Why study quasars and their hosts ?

• QSO are the most powerful sources of coherent energy in the Universe

• quasars resides in the nuclei of massive galaxies

• SBH are believed to exist in all massive spheroids (galaxies)

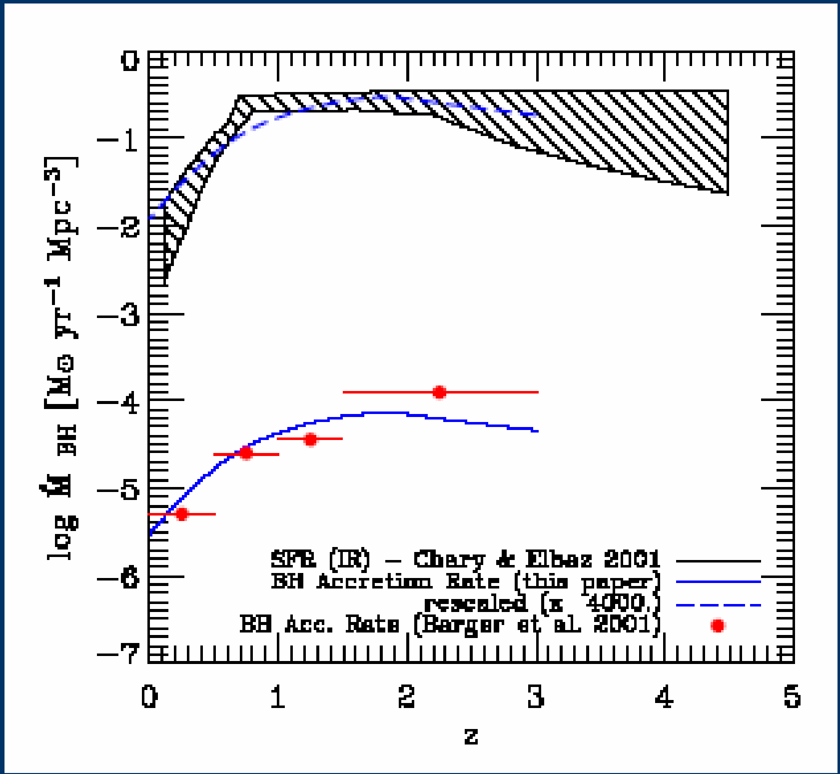
• there is a strong link between the formation and evolution of SBH and galaxies

• QSOs are the only non-transient sources that can be observed at very high redshift

Highlights the processes of formation and evolution of the galaxies

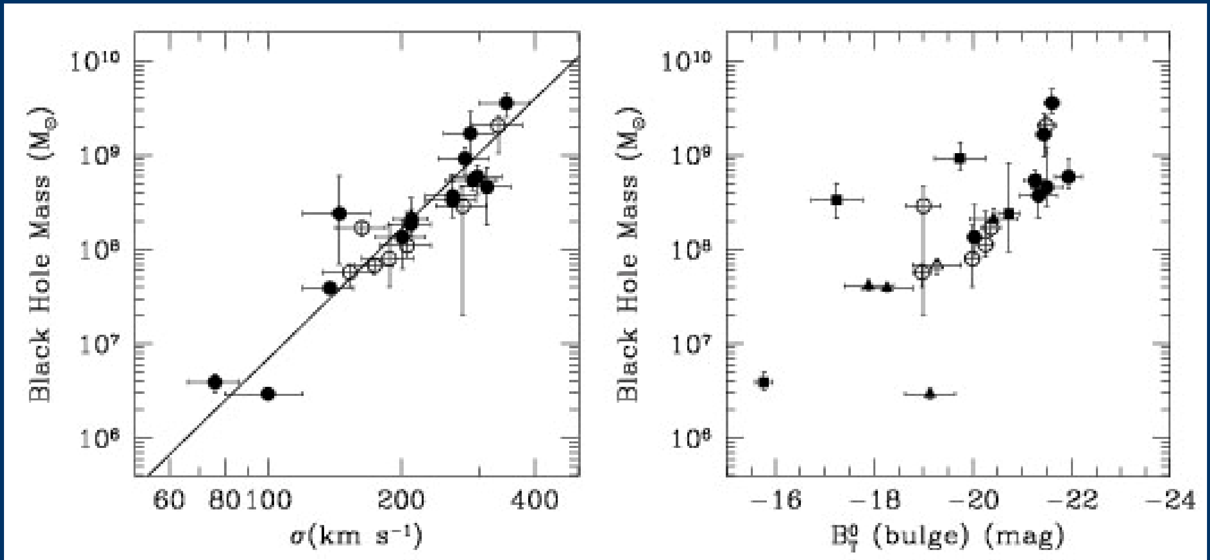
QSO can probe of the distant Universe

The AGN - galaxy connection



similar BH accretion rate and cosmic SFR histories

M(BH) - L(sph) – sigma relations



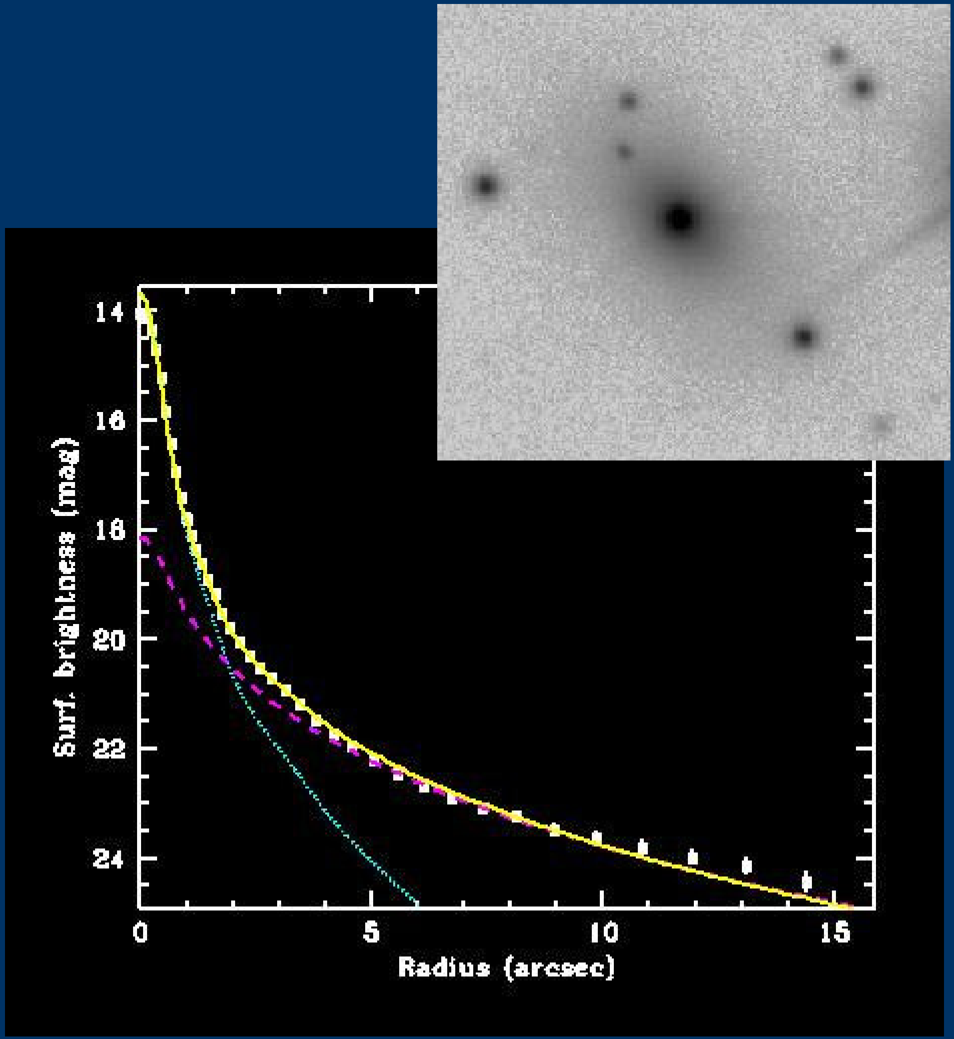
link between formation and evolution of massive galaxies and the nuclear activity

Detection of Quasar hosts

***The issue:* detection of the faint extended emission surrounding a bright point source**

Requirements

- narrow PSF; excellent seeing for GB data
- high throughput (to detect faint SB);
- IR observations for high z sources
- optimal characterization of PSF; stable instrument, adequate FoV



Host galaxies of QSO at low redshift

The observational milestones

- Photographic plates studies (<1980)
- CCD images (>1980)
- NIR data (>1990)
- HST imaging (>1995)
- Keck,VLT,… 8m class telescopes (>2000)
- AO @ 8-10m telescopes (>2004)

Quasar hosts at low redshift

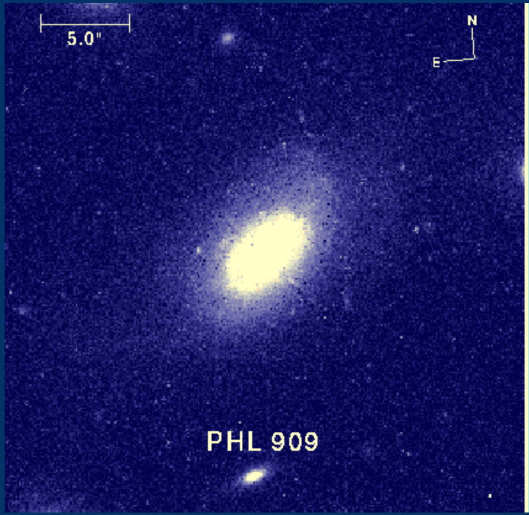
The Ground Based view

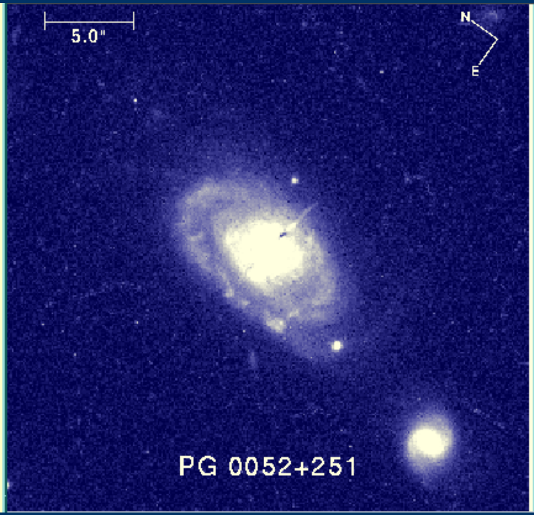
- ~100 objects resolved at $z < 0.5$
- most of the resolved objects are at $z < 0.3$!!!

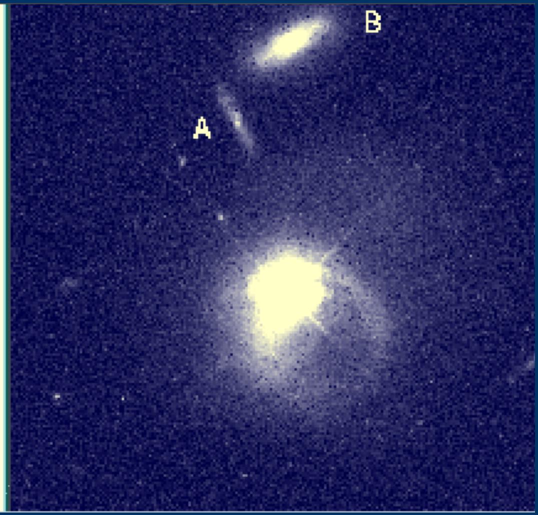
1. Hutchings et al 1989 : V, R ($z<0.3$)
2. Veron-Cetty &Woltjer 1990 : R, I ($z<0.4$)
3. McLeod & Rieke 1994;1995 : NIR ($z<0.3$)
4. Taylor et al. 1996 : NIR ($z<0.3$)
5. Kotilainen Falomo & Scarpa 1998 : NIR ($0.5<z<1.0$) FSRQ
6. Percival et al 2001 : NIR ($0.25<z<0.45$) high luminosity
7. Kotilainen & Falomo 2000 : NIR ($0.5<z<1.0$) SSRQ

Quasar hosts at low redshift

The HST view





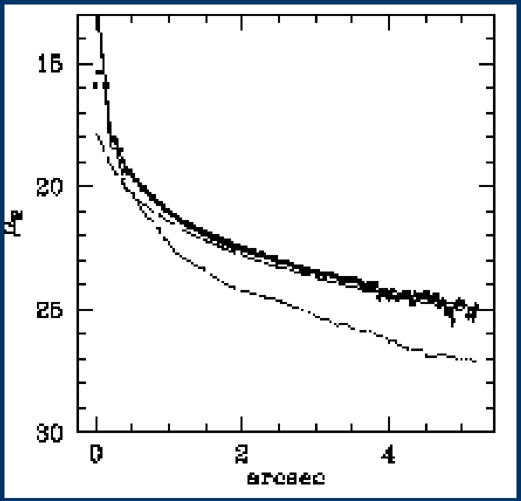


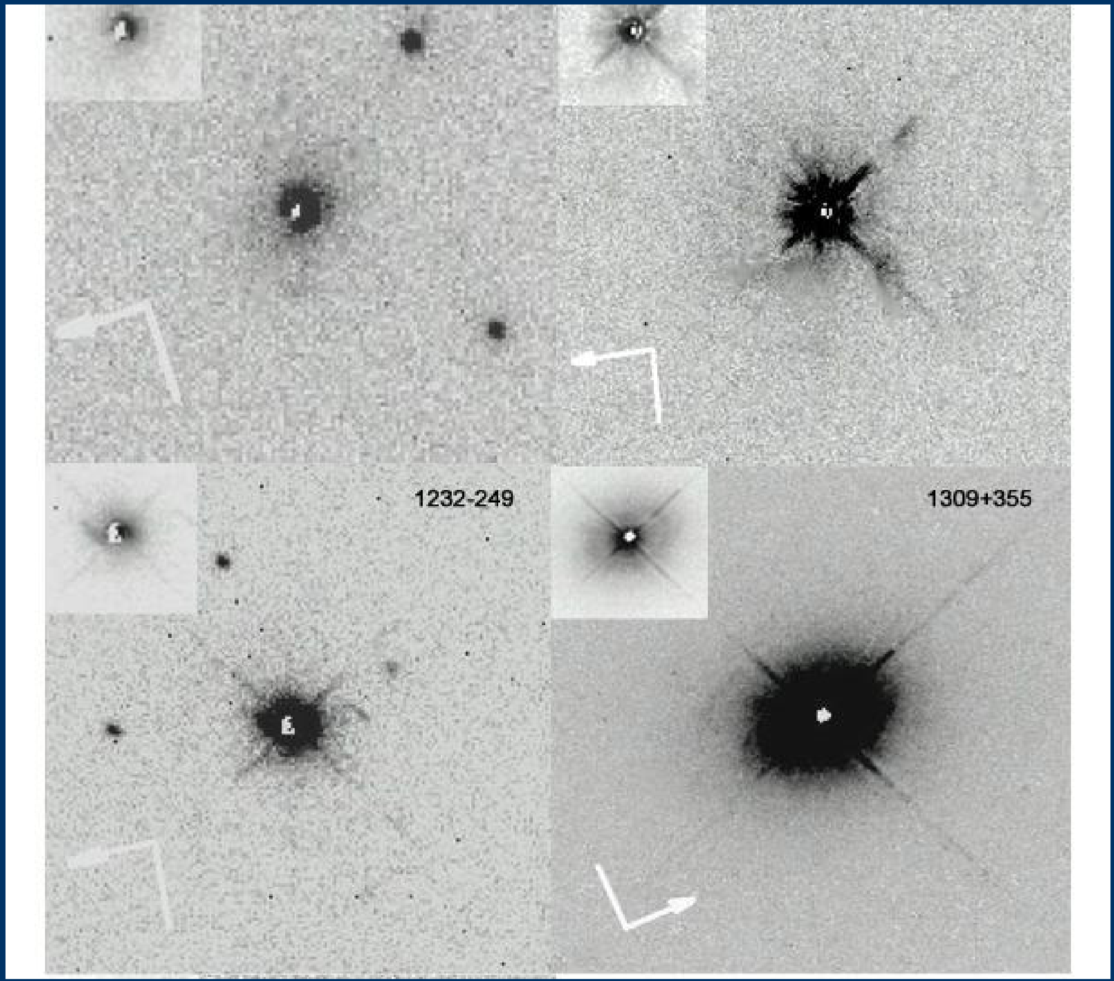
- 109 objects resolved at z <0.7 (mostly WFPC2 + few NICMOS)
- most of the objects are at z < 0.5 (RLQ & RQQ)
- morphology details (S, E, companions,…)

1. Bahcall et al 1996;1997; Kirhakos et al 1999 (z<0.3)
2. Disney et al 1995; Boyce et al 1998 (z < 0.3)
3. Hutchings et al 1999 ()
4. Hooper et al 1997 (z ~ 0.5)
5. Dunlop et al 1999; 2003 (z < 0.3)
6. Pagani et al 2003 (z<0.5), Hamilton et al 2004 (z<0.45)

Quasar hosts at low redshift

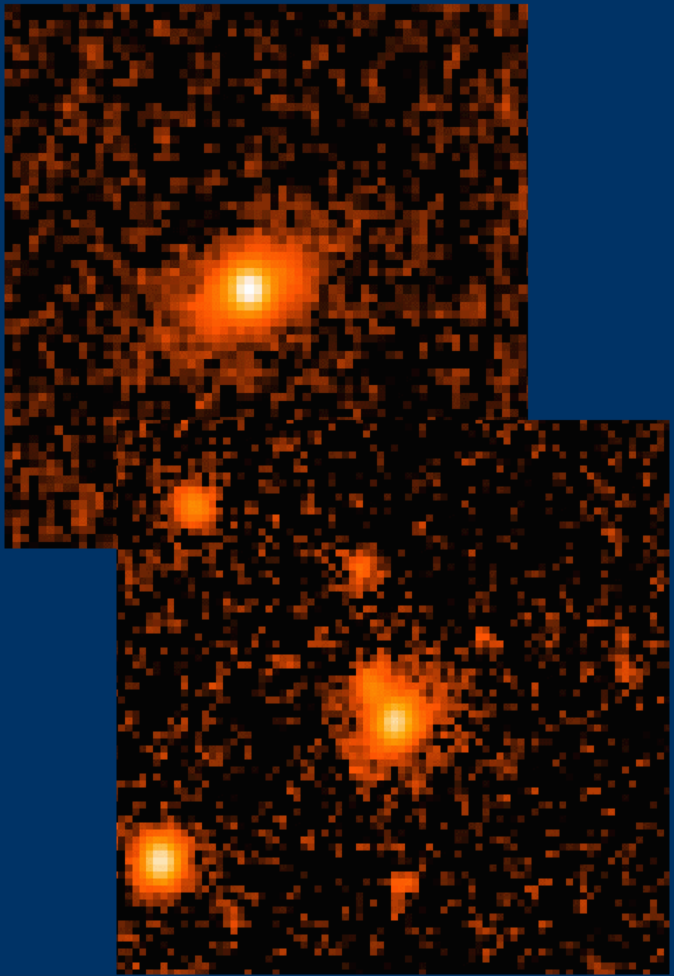
Examples from HST (z < 0.5)



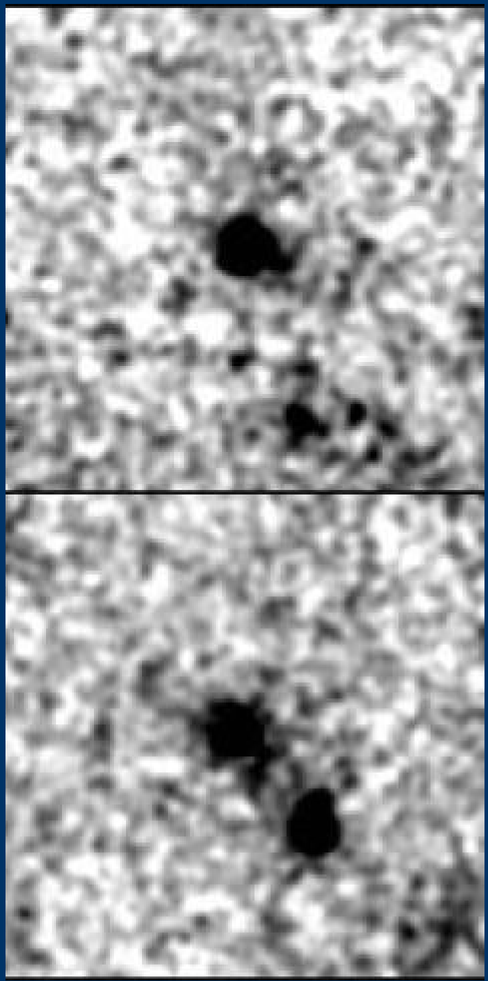


34 (z<0.5) RLQ by HST WFPC2: Pagani Falomo & Treves 2003 ApJ 596 830

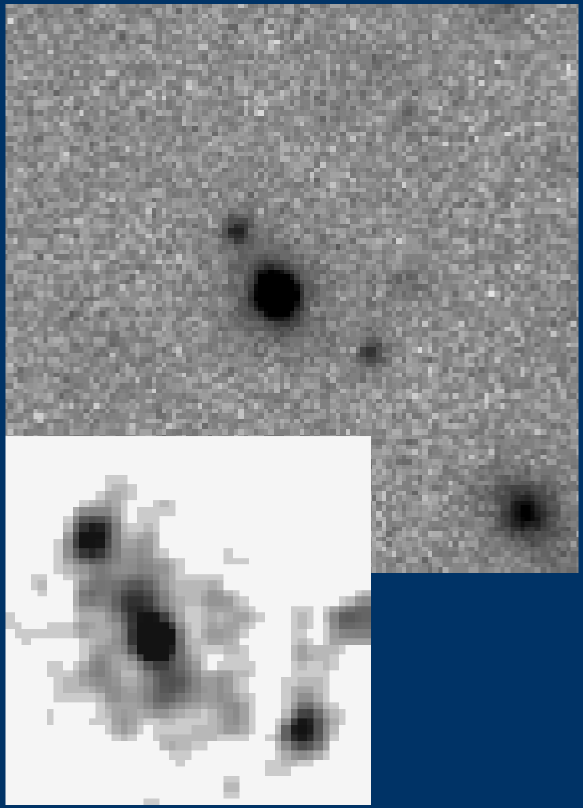
Host galaxies of QSO at high redshift
($1<z<2$)



NTT z ~ 1



HST z ~ 2



VLT z ~ 1.5

QSO host galaxies at high redshift (z> 1.0)

up to year 2000

Ground based images:

- 6 RQQ at <z> ~ 2.5 (Lowenthal et al 1995) ⇨ NO detection
- 6 RLQ at <z >~ 2.3 (Lehnert et al 1992) ⇨ $\langle M_H \rangle \sim -28.8$
- 3 RLQ at <z> ~ 1.5 (Falomo et al 2001) ⇨ $\langle M_H \rangle \sim -27.6$

VLT

HST images (NICMOS)

- 5 RQQ at z ~ 2-3 (Ridgway et al 2001) ⇨ $\langle M_H \rangle \sim -26$
- 5 RQQ at z ~ 2 (Kukula et al 2001) ⇨ $\langle M_H \rangle \sim -26.5$
- 4 RLQ at z ~ 2 (Kukula et al 2001) ⇨ $\langle M_H \rangle \sim -27.7$

(H=50 q=0)

Imaging of QSO at z= 1 to 2

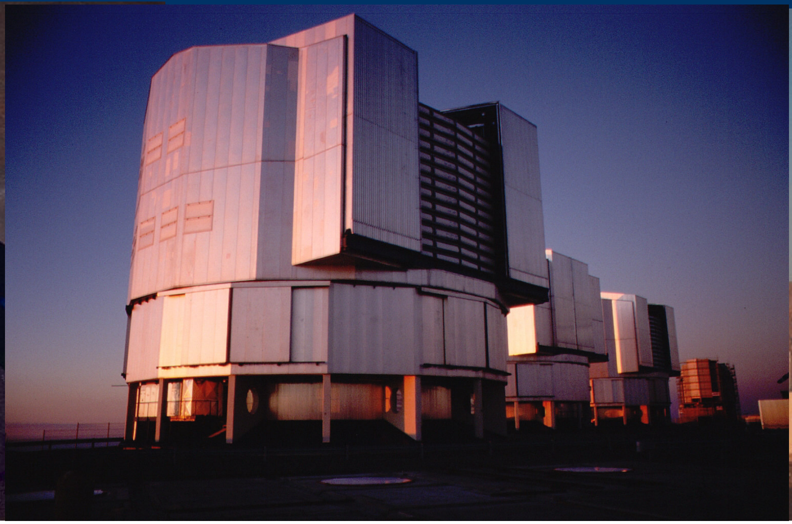
… the NEW era …

…the 8-10 m class telescopes…

Keck

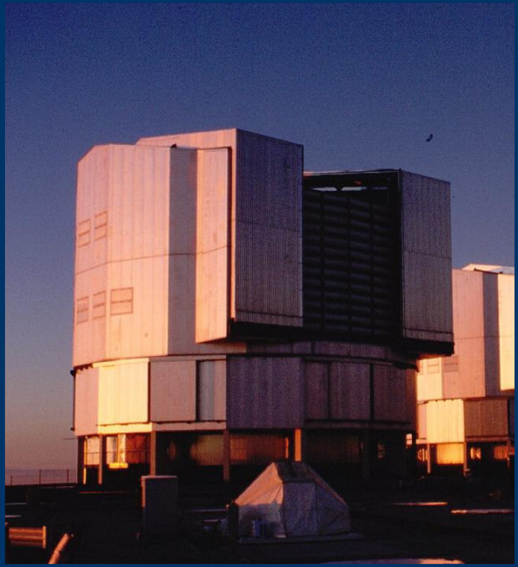
VLT

Gemini



VLT imaging of QSO at z= 1 to 2

The VLT QSO sample



- 40 QSO 1<z<2 (32 observed)
- well observable from Paranal & w/ bright star(s) for PSF definition
- RLQ and RQQ subsamples matched for redshift and nuclear luminosity

- Campaign I - 2002 : 17 observed
  (10 RLQs + 7 RQQs) high Lum

[Falomo et al 2004 ApJ 604, 495]

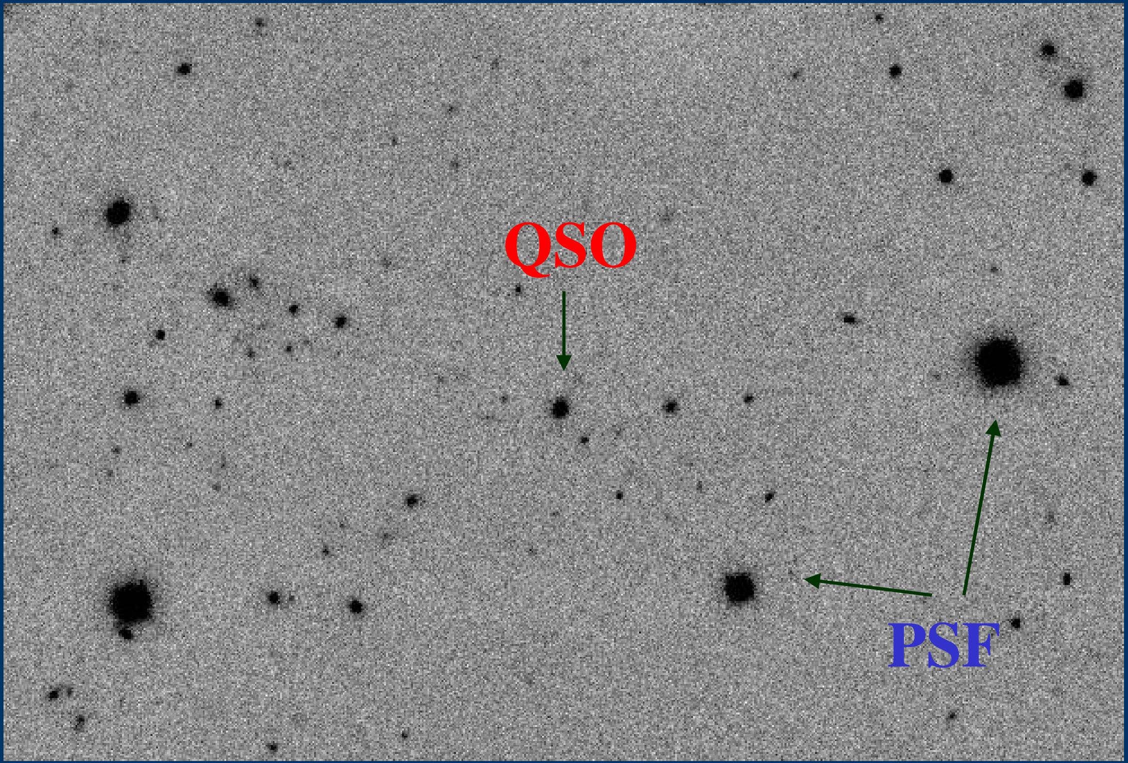
- Campaign II - 2004 : 15 objects
  (9 RLQs + 6 RQQs) low Lum

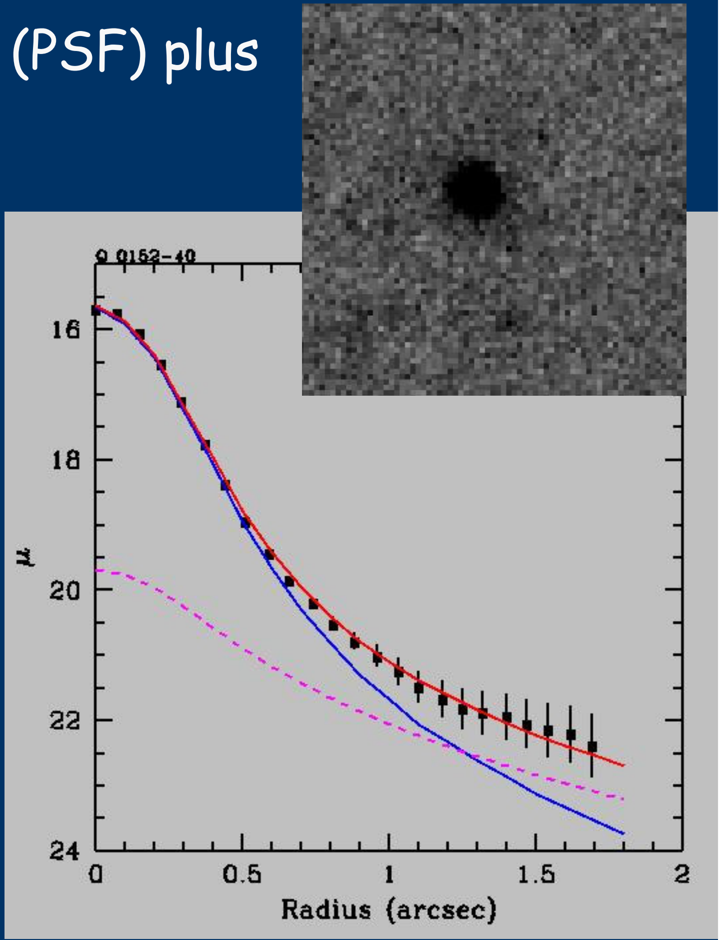
[Kotilainen et al 2006 in prep.]

VLT imaging of QSO at z= 1 to 2

Observations and Analysis

- Service mode observations ISAAC + H,K filter
- Excellent seeing (median FWHM 0.4 arcsec)
- Radial brightness profile fitted w/ nucleus (PSF) plus elliptical host galaxy

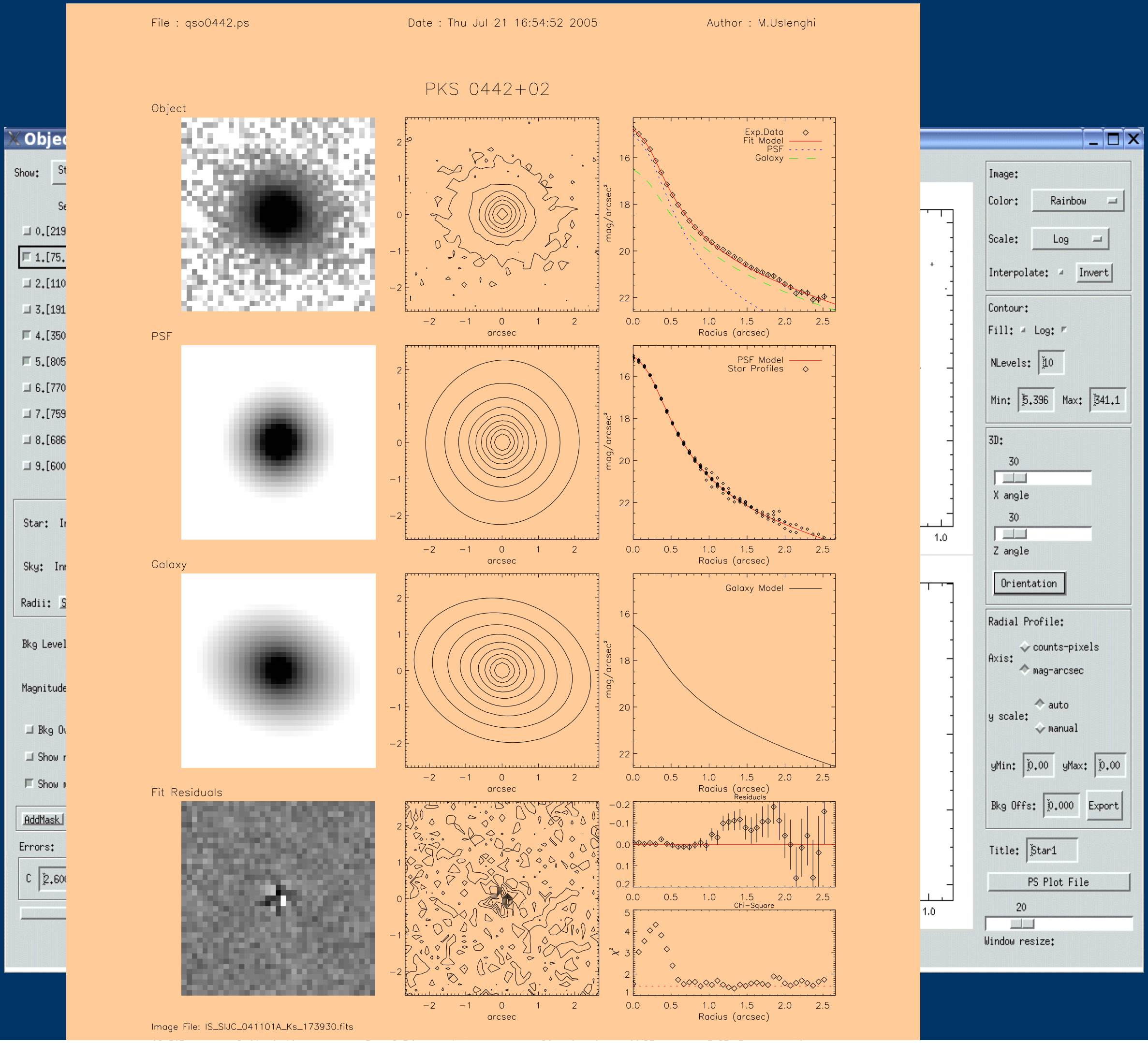




Data Analysis of AO images

2005 © M. Uslenghi, R. Falomo

New AIDA – Astronomical Image Decomposition & Analysis



Designed to perform 2-D model fitting of Quasar images including AO data

Detailed modeling of the PSF and its variations

VLT imaging of QSO at z= 1 to 2

Results

- 30 out of 32 observed QSO are resolved (!!)
- nuclear & host galaxy luminosity well determined
- … but scale-length poorly constrained

Average host luminosity (H=70 $\Omega m= 0.3$ $\Omega_\Lambda=0.7$)

	high L	low L	
RLQ $\langle M_K \rangle =$	-26.7	-26.3	$\langle z \rangle = 1.51$
RQQ $\langle M_K \rangle =$	-26.2	-25.7	$\langle z \rangle = 1.52$

RLQ hosts are ~0.5 mag brighter than RQQ hosts

Small dependence on nuclear luminosity

VLT imaging of QSO at z= 1 to 2

Host galaxy luminosity

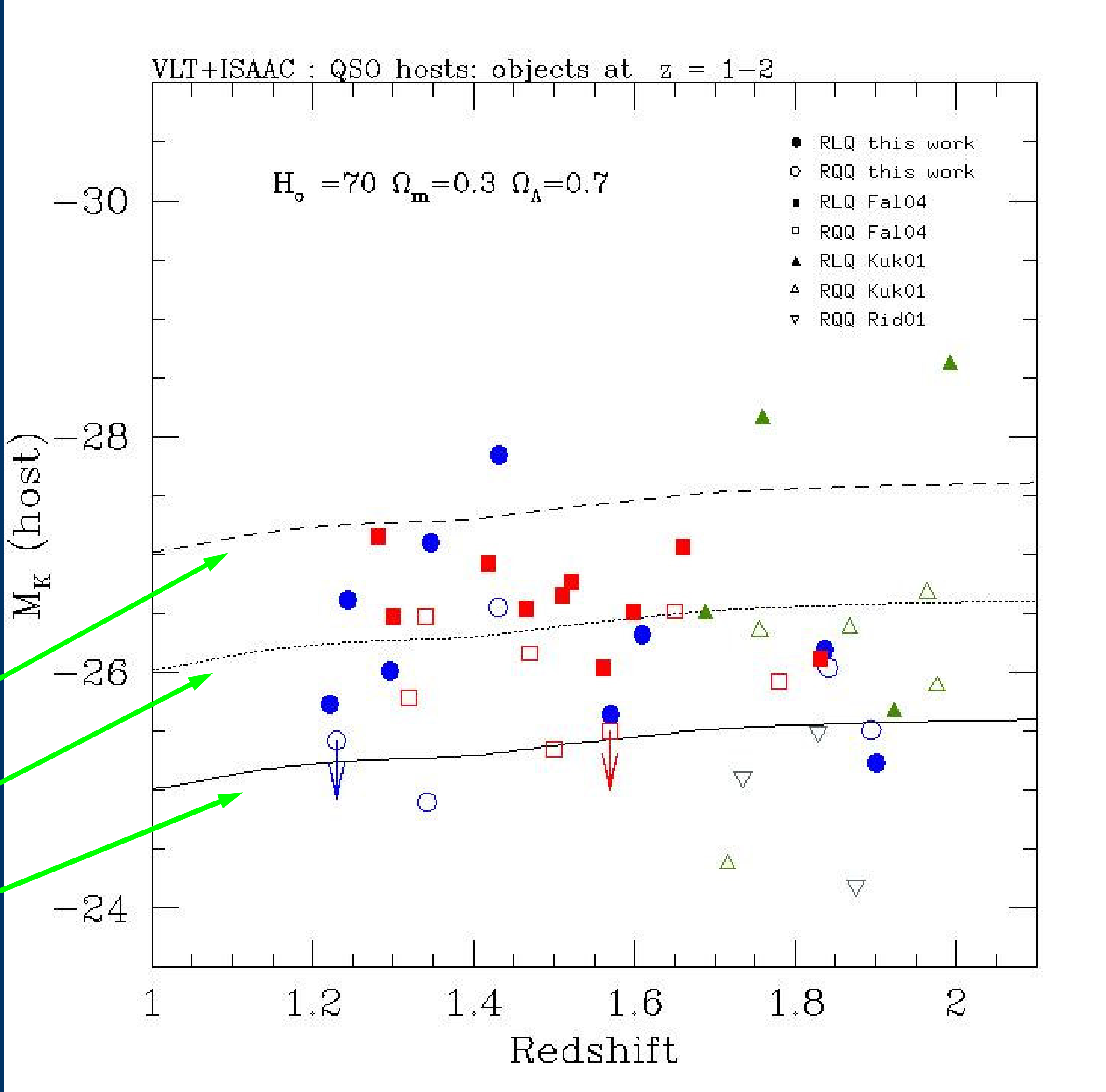
32 QSOs at

1<z<2

VLT+ISAAC

H or K filter

Seeing 0.4"-0.5"

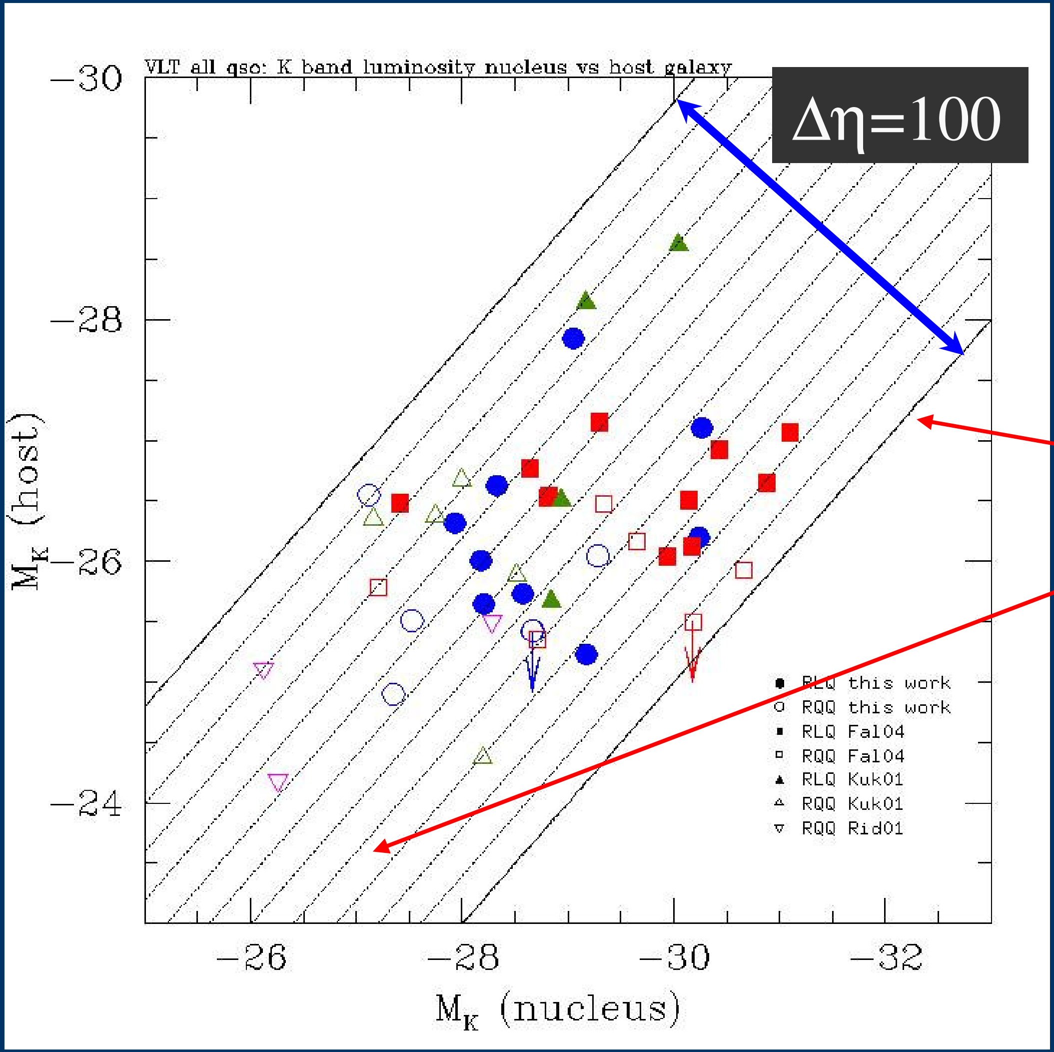


M* - 2

M* -1

M*

Nuclear vs host galaxy luminosity



$M_K(\text{host}) \rightarrow M_{BH}$

$M_{BH} \rightarrow L_{Edd}$

$M_K(\text{nuc}) \rightarrow L_{bol}$

$\eta = N/H \sim L/L_{Edd}$

η = constant

$<\log \eta> =$

1.04 +- 0.40 (RLQ, low L)
1.36 +- 0.33 (RLQ, F04)

1.00 +- 0.44 (RQQ, low L)
1.32 +- 0.37 (RQQ, F04)

Wide range of η irrespective of radio power and same average value

Host luminosity slightly correlated with nuclear power (RLQs)

Cosmic evolution of quasar hosts

Expectations from the hierarchical QSO-galaxy formation scenario

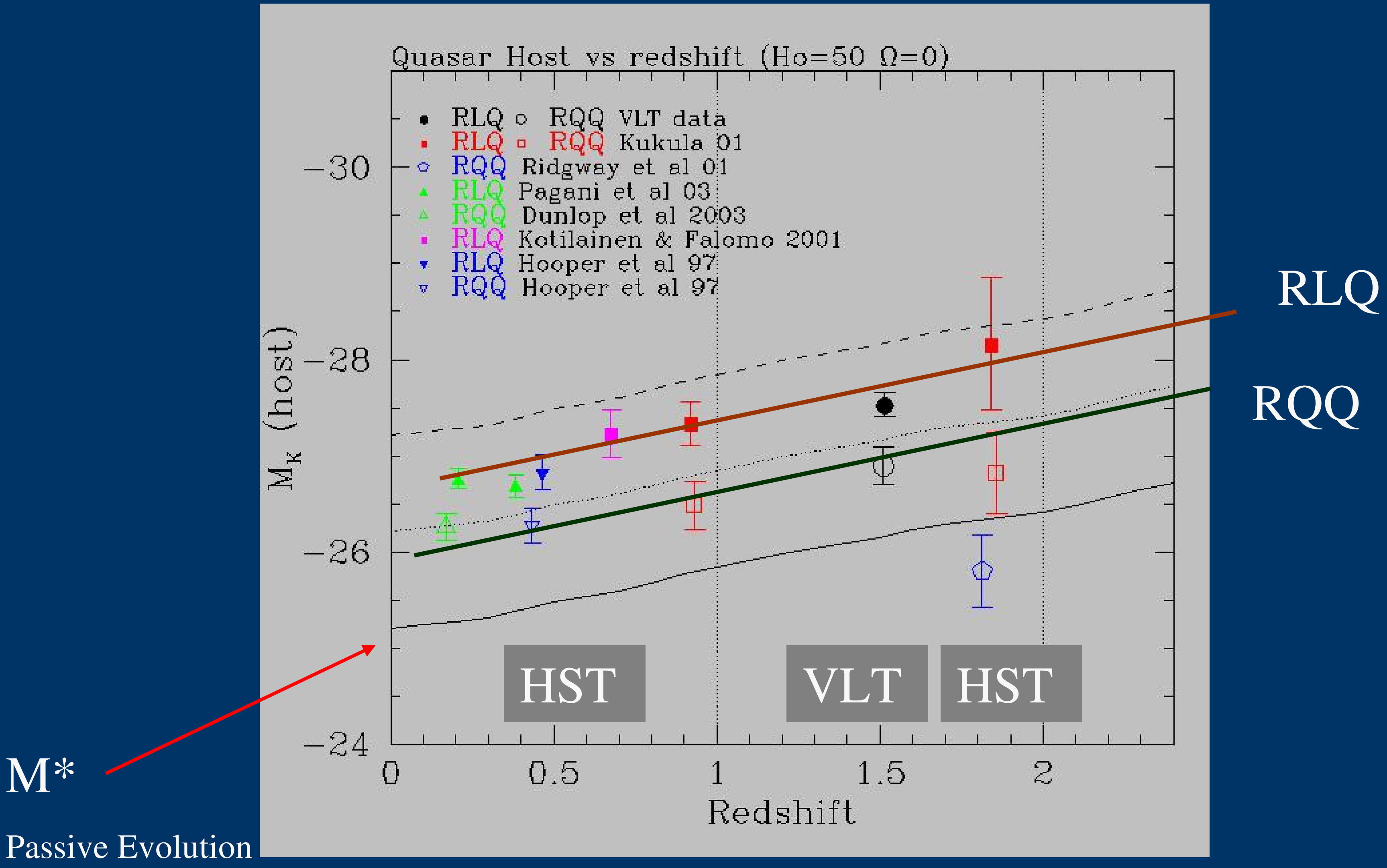
semi-analytical models of joint SBH and galaxies formation and evolution predict that star formation occurs in relatively small galaxies that later merge to make bigger objects.

BUT the observations show too many massive galaxies at high redshift

quasars should be found in progressively less luminous host galaxies between $z=0$ and $z=2-3$ $\Delta M \sim 1.5-2.0$

Cosmic evolution of quasar hosts up to z = 2

From z=2 to the local Universe



Falomo et al **2004 ApJ 604, 495**

Cosmic evolution of quasar hosts up to z = 2

Main conclusions

- quasar hosts are encompassed in the range M* to M*-2
- RLQ hosts are ~ 0.6 mag brighter than RQQ hosts (this seems to keep from z=2 to z=0)
- QSO hosts are already well formed at z=2 (assuming fixed M/L) ;
- no evidence for the expected drop in mass by the hierachical merging models of galaxies-AGN formation

Falomo et al. 2004 ApJ 604, 495
Kotilainen et al 2006 ApJ (in prep.)

QSO host at higher redshift (z > 2)

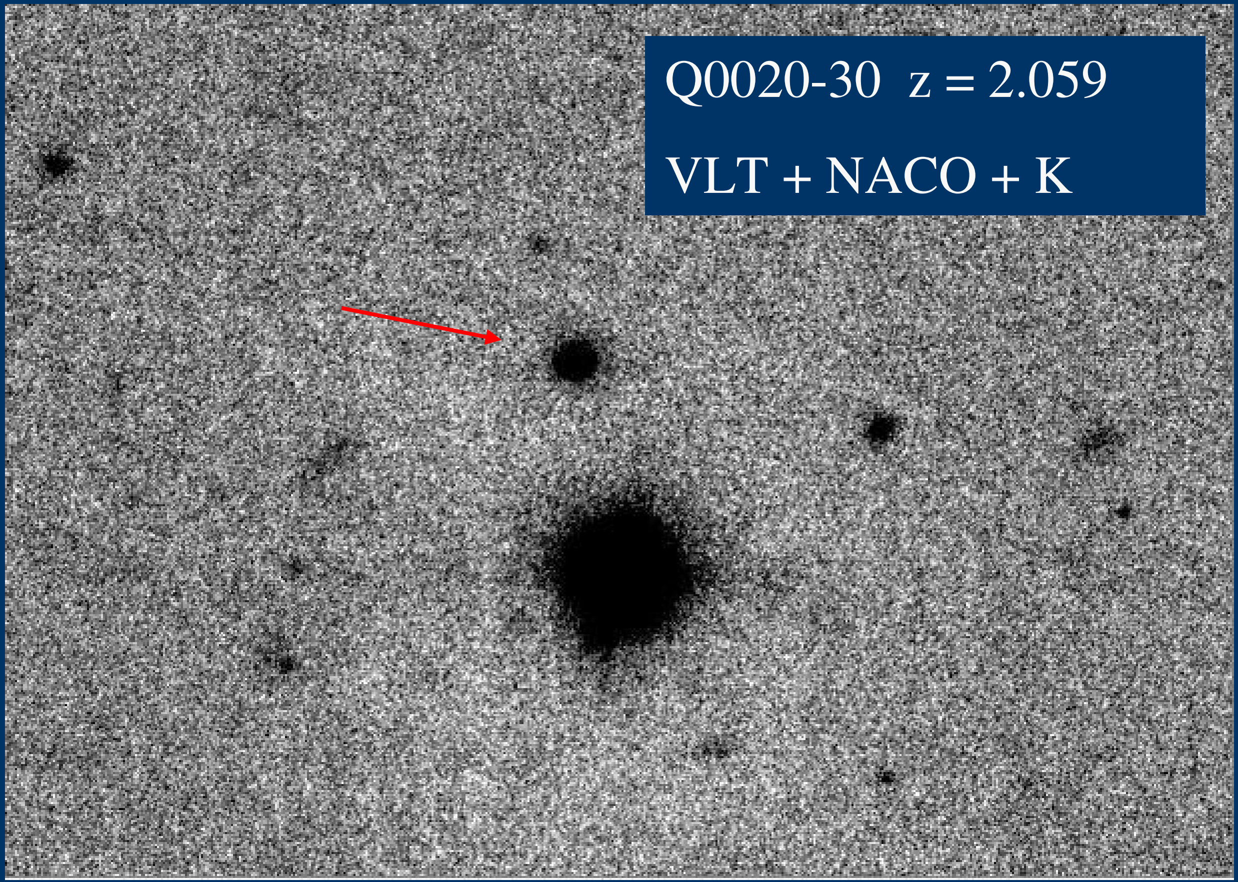
…???…. a mess …???..

… a possible cure ….

Adaptive Optics imaging @ 8-10m telescopes

Adaptive Optics Imaging of Quasar Hosts

An alternative (more direct) approach



AO imaging of QSO

Pros and Cons

Pros

- high contrast features in the surrounding environments can be resolved and detected (low z objects)
- a sharp PSF helps to reduce the bright core and thus to resolve & detect the surrounding host galaxy (high z objects)

Cons

- the PSF is less stable and generally more complex
- need of a relatively bright Guide Star close to the target to enable AO corrections
- FoV is small (standard AO, but MCAO is promising)

AO imaging of QSO

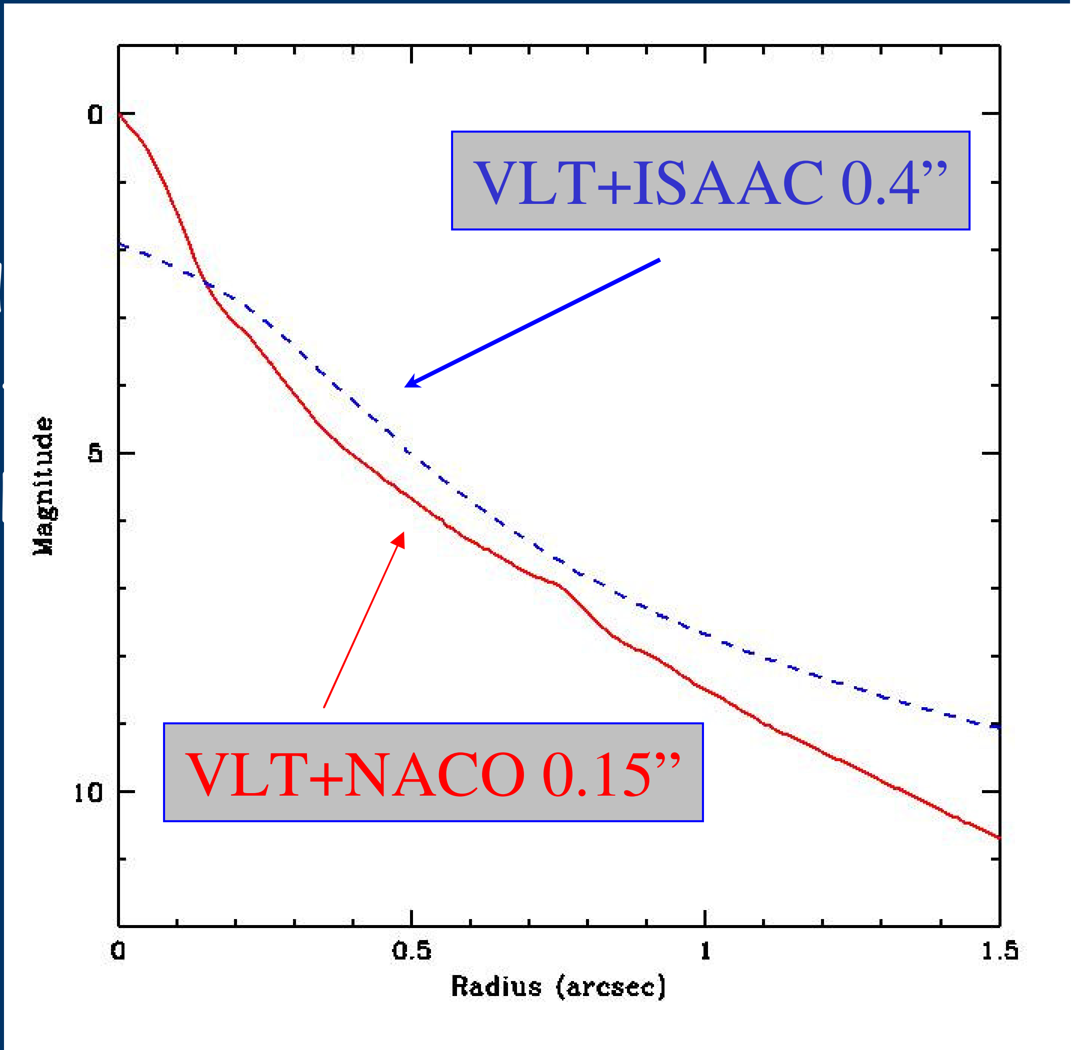
The key issue: PSF shape and its determination

Anisoplanaticism

- significant change of th
- FWHM and elongation d
- requires to have adequa
- detailed modeling of PS

The AO - PSF shape

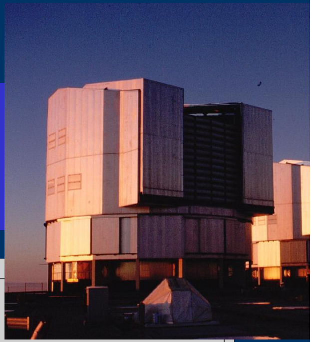
- sharp peak
- narrow core



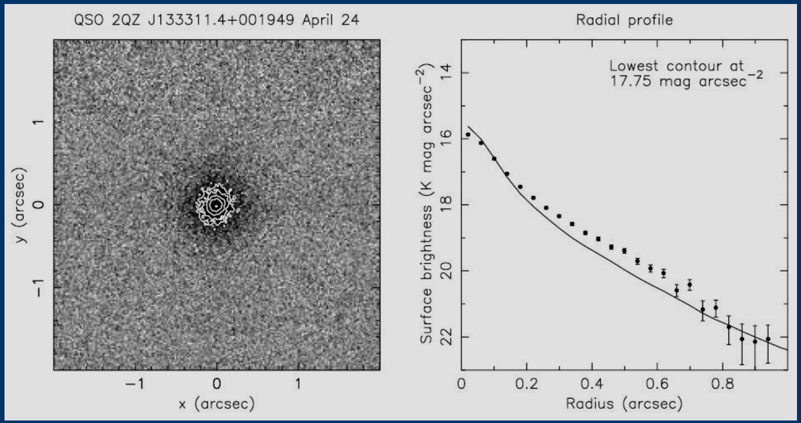
Examples of resolved QSO at z > 1 using AO imaging

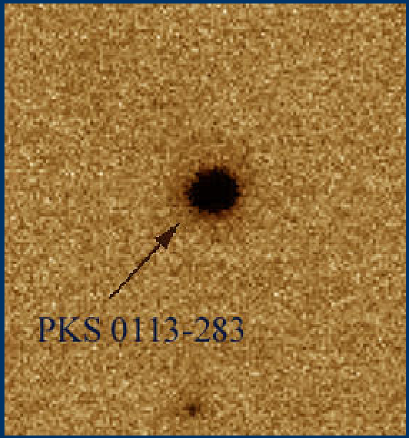
- Arextaga et al 1998: 1 RQQ @ z ~ 2 [ESO 3.6 + COME-ON+K]
- Hutchings 1999: 2-3 QSO @ z ~ 1-4.2 [CFHT + PUEO + JHK]
- Kuhlbrodt et al 2005: 3 RQQ @ z ~ 2 [ESO 3.6 + ADONIS+K]

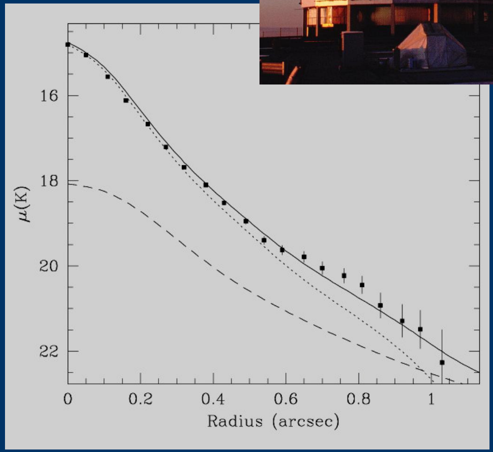
… preliminary and/or uncertain results…



Croom et al 2004: 1 RQQ @ z ~ 1.9 [Gemini-N + Okupa +K]
Falomo et al 2005 : 1 RLQ @ z~ 2.6 [VLT + NACO + K]







Scarpa et al 2005 -*The Messenger*

VLT + NACO images of QSO at z > 2

The VLT + NACO sample of z > 2 QSO

- QSO @ 2<z<3 from Veron&C-V AGN catalogue (~ 50000 objects)
- nearby *bright* star for AO correction
- well observable from Paranal & w/ bright star(s) in the FoV for PSF characterization

Under these conditions less than 30 targets can be observed.

5 objects observed till now (Sept. 2005)

Radio Loud Quasar at z ~ 2.5

FSRQ

The QSO PKS 0113 -283

z = 2.555

V = 20.0

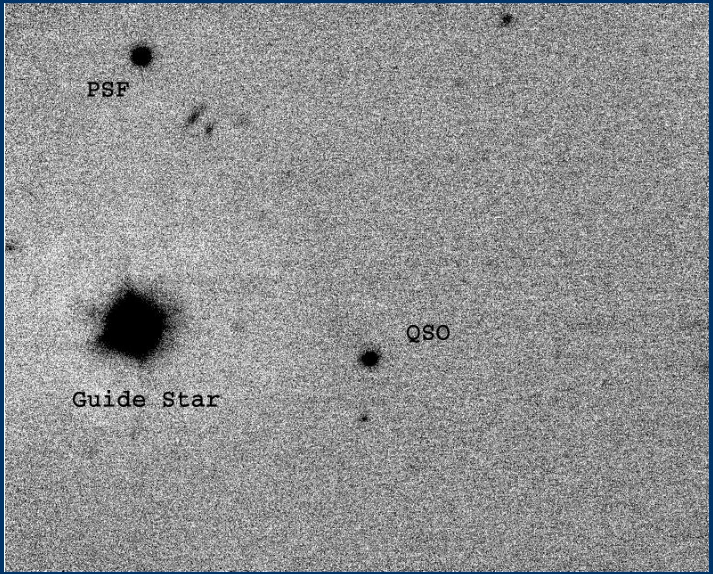
M_B = -26.8

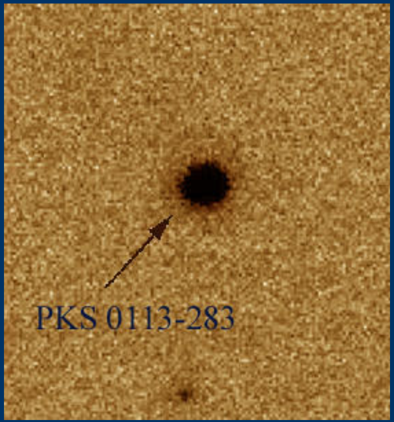
Host galaxy

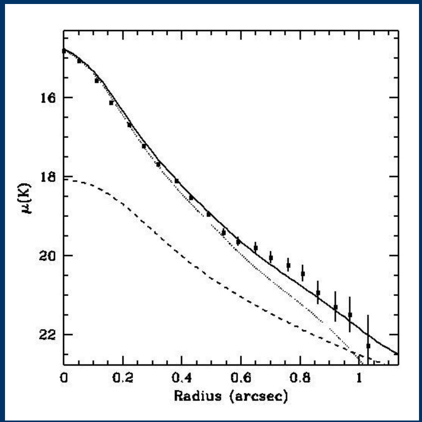
$M_K = -27.6$

Re = 7.5 kpc

(H=70 Ωm= 0.3 ΩΛ=0.7)







Falomo et al 2005 AA 434 473

Scarpa et al 2005 -*The Messenger*

Radio Loud Quasar at z ~ 3

The QSO WGA J0633.1-2333 FSRQ

z = 2.928

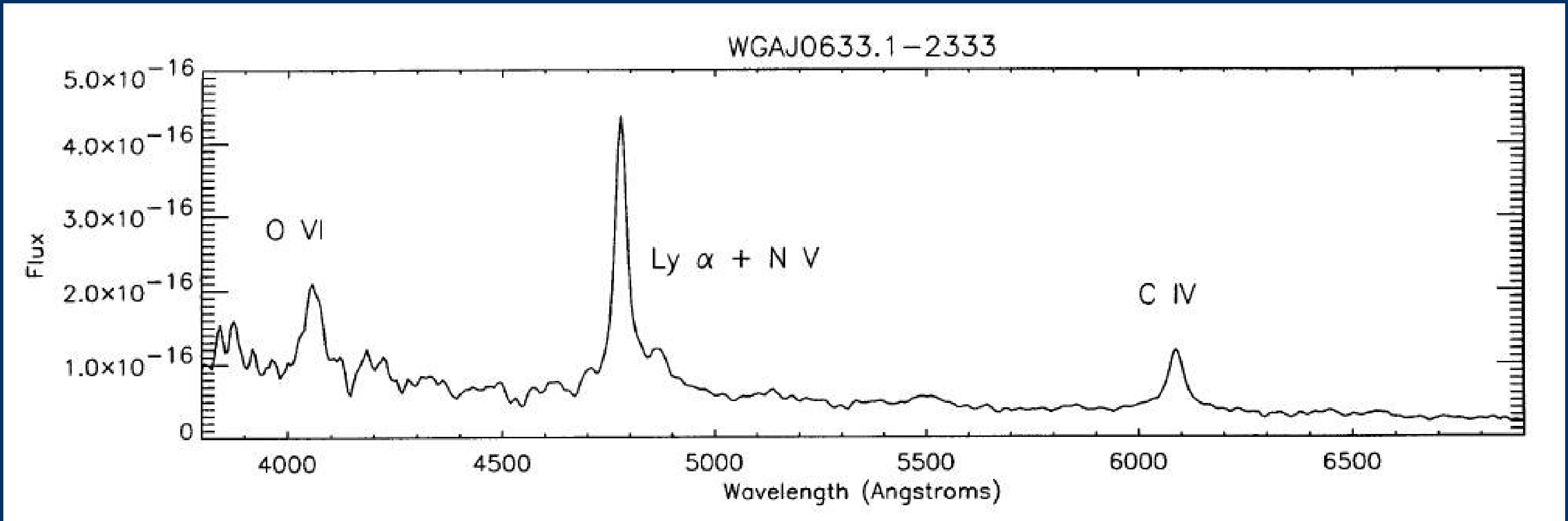
F(6cm) = 99 mJy

V = 21.5

$\alpha_R < 0.7$

M_B = -26.0

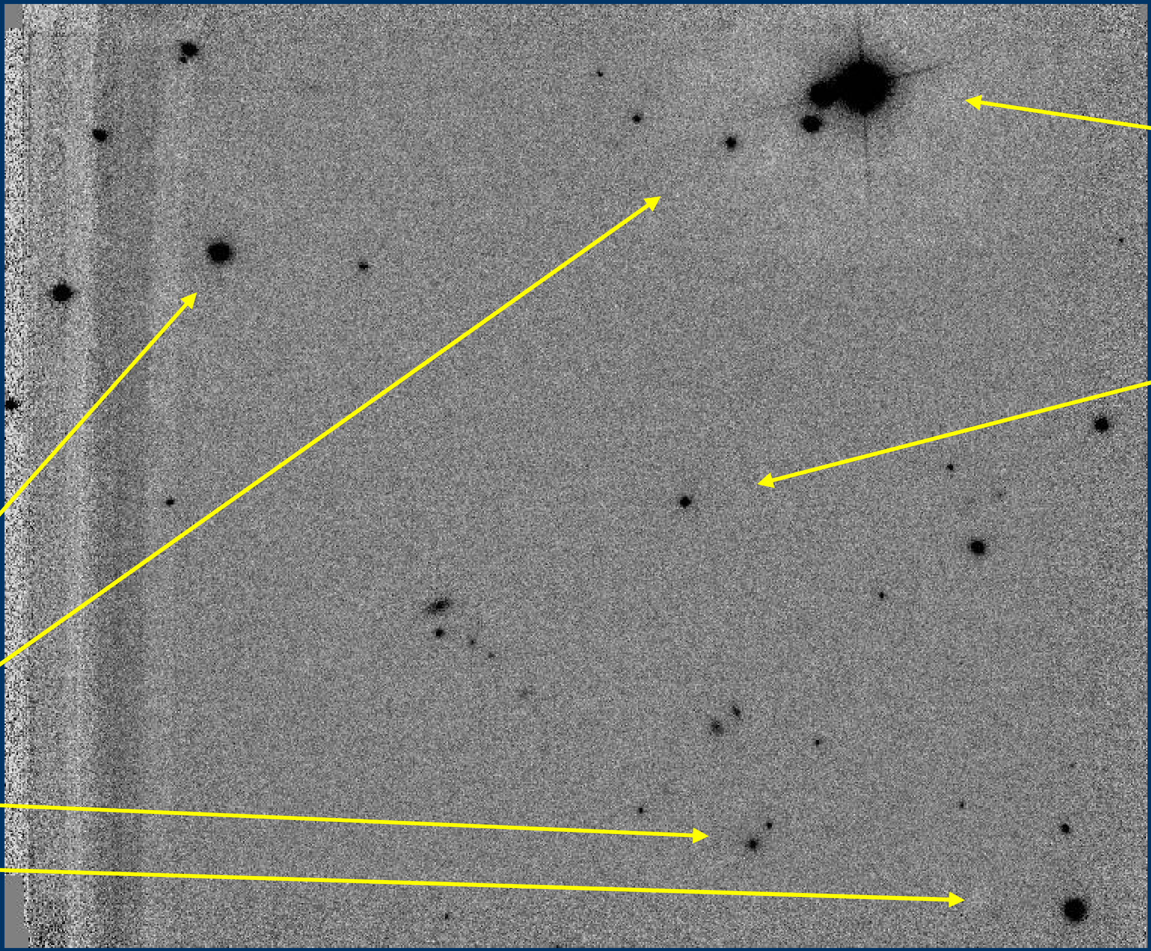
(H=70 Ωm= 0.3 ΩΛ=0.7)



Perlmann et al 1998

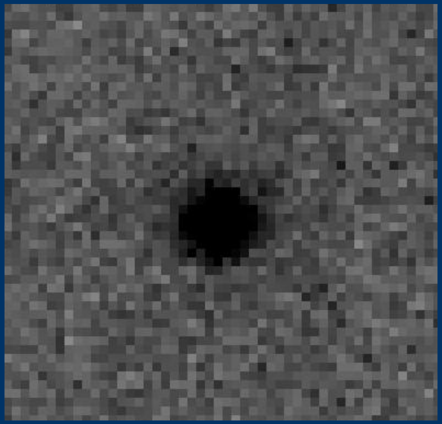
Radio Loud Quasar at z ~ 3

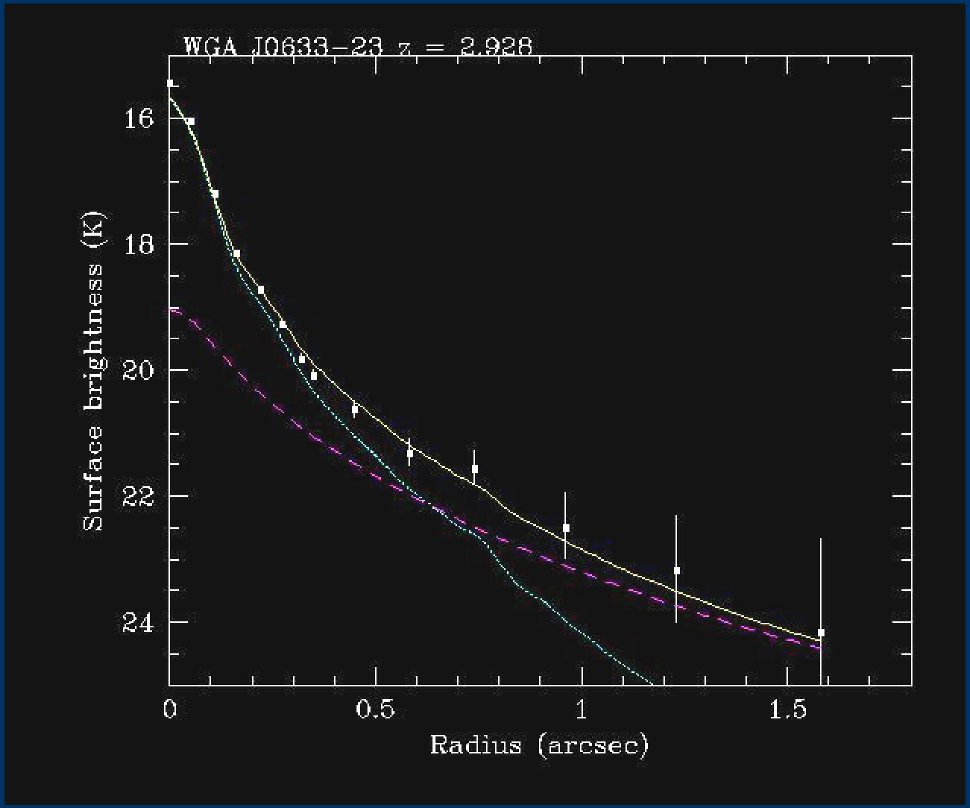
NACO Ks image WGA J0633.1-2333



Radio Loud Quasar at z ~ 3

NACO image WGA J0633.1-2333





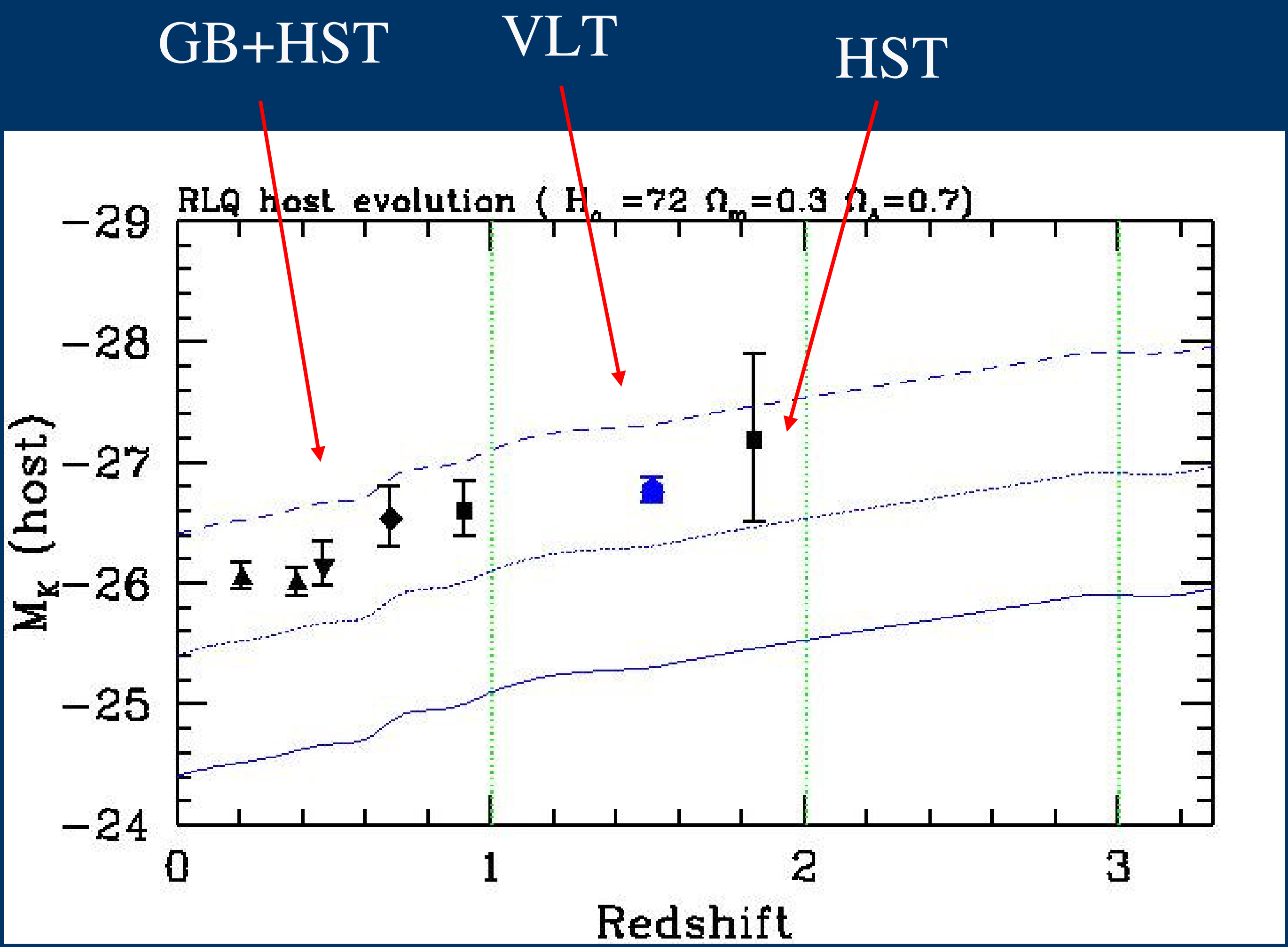
Host galaxy

$M_K = -27.1$

Re = 6.5 kpc

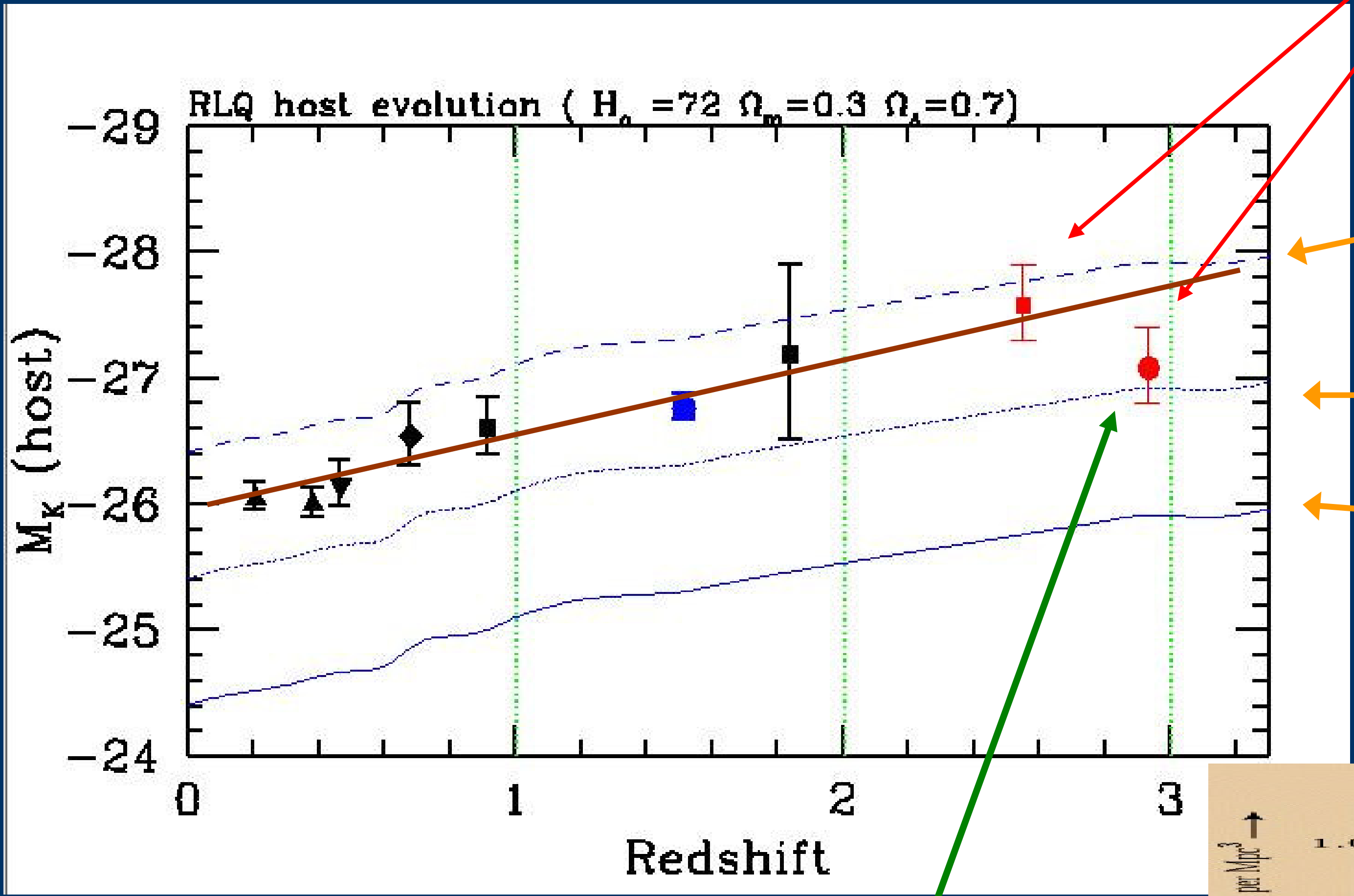
(H=70 Ωm= 0.3 ΩΛ=0.7)

Cosmic evolution of RLQ hosts up to z ~ 2



Cosmic evolution of RLQ hosts up to z ~ 3

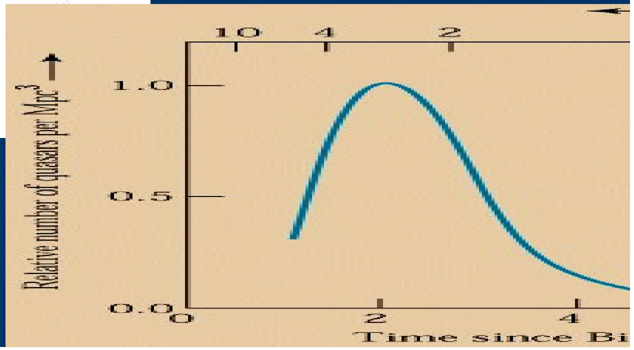
VLT+AO



M*-2

M*-1

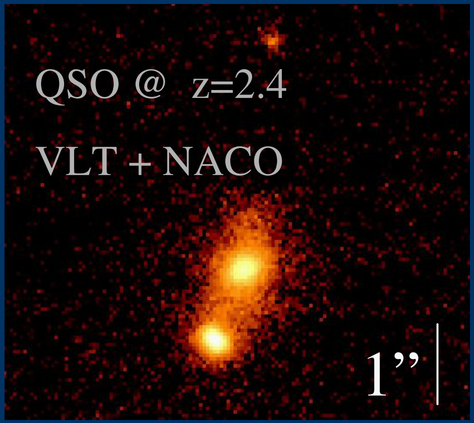
M*



Possible drop of luminosity (mass) at z = 3

…close to the peak of QSO

Cosmic evolution of quasar hosts



Open questions & Future work

1. Improve statistics of quasar hosts at $z > 2$ and explore full range of nuclear luminosity (35h @ VLT in P77)
2. Difference between RLQ and RQQ host properties at $z > 2$ (no/few RQQ resolved at $z > 2$)
3. Explore the M_{BH}/M_{bulge} at high redshift(5n @ ESO3.6 in P77)
4.
5. Color of distant quasar hosts (a first clue for the stellar population)