Extremely Red Objects (EROs)

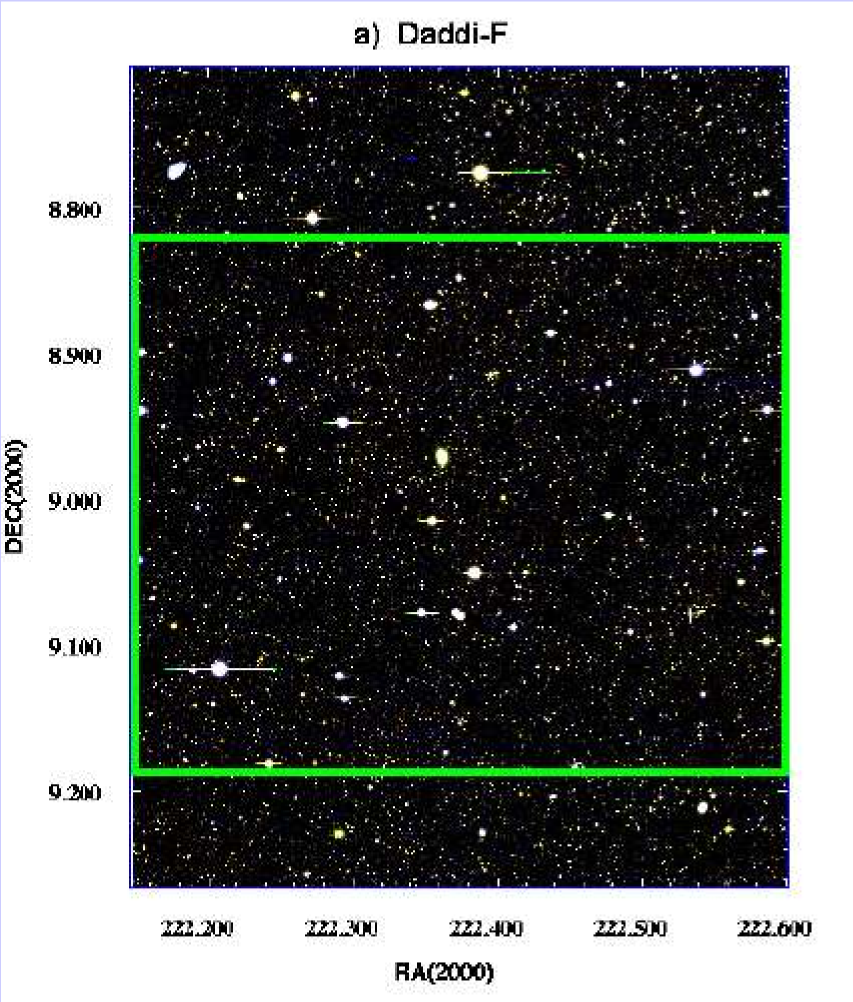
Jan 25. 06

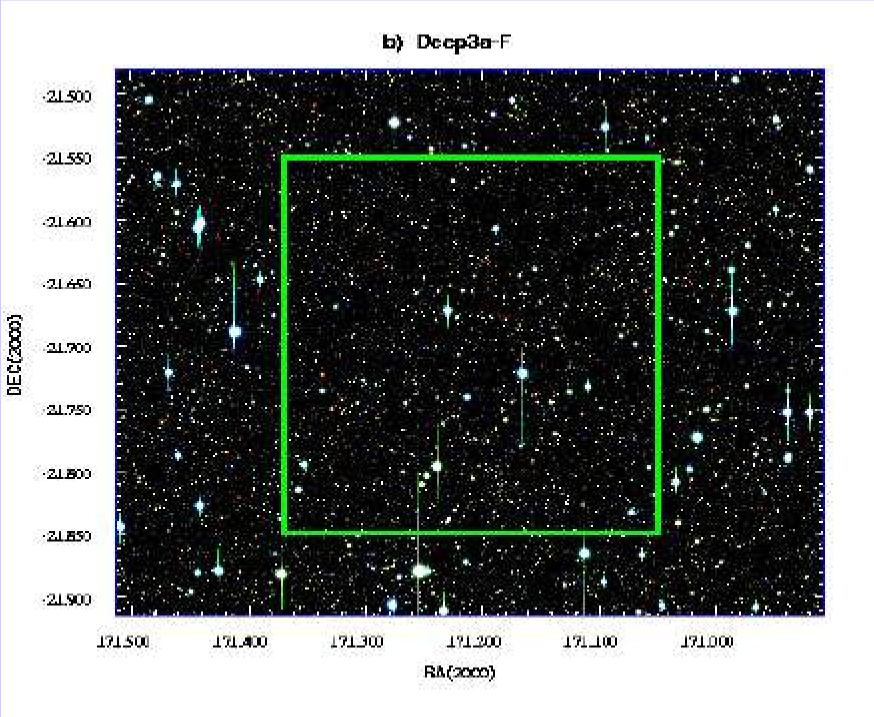
“A wide Area Survey For High-Redshift Massive Galaxies. I.Number counts And Clustering of BzKs And EROs”

X. Kong et al. 2005

Astro-ph/051299 v1 11 Oct2005

Fields :





$$\alpha = 11^{h}24^{m}50^{s}\ ,\ \delta = -21^{\circ}42^{\wedge}00^{\wedge}$$

$$(320\ \ arcmin^{2})\ \ ,\ \ (K_{s} < 20)$$

$$\alpha = 14^{h}49^{m}2^{s}\ \ ,\ \ \delta = 09^{\circ}00^{\wedge}00^{\wedge}$$

$$(600\ \ arcmin^{2})\ ,\ (K_{s}<18.8)$$

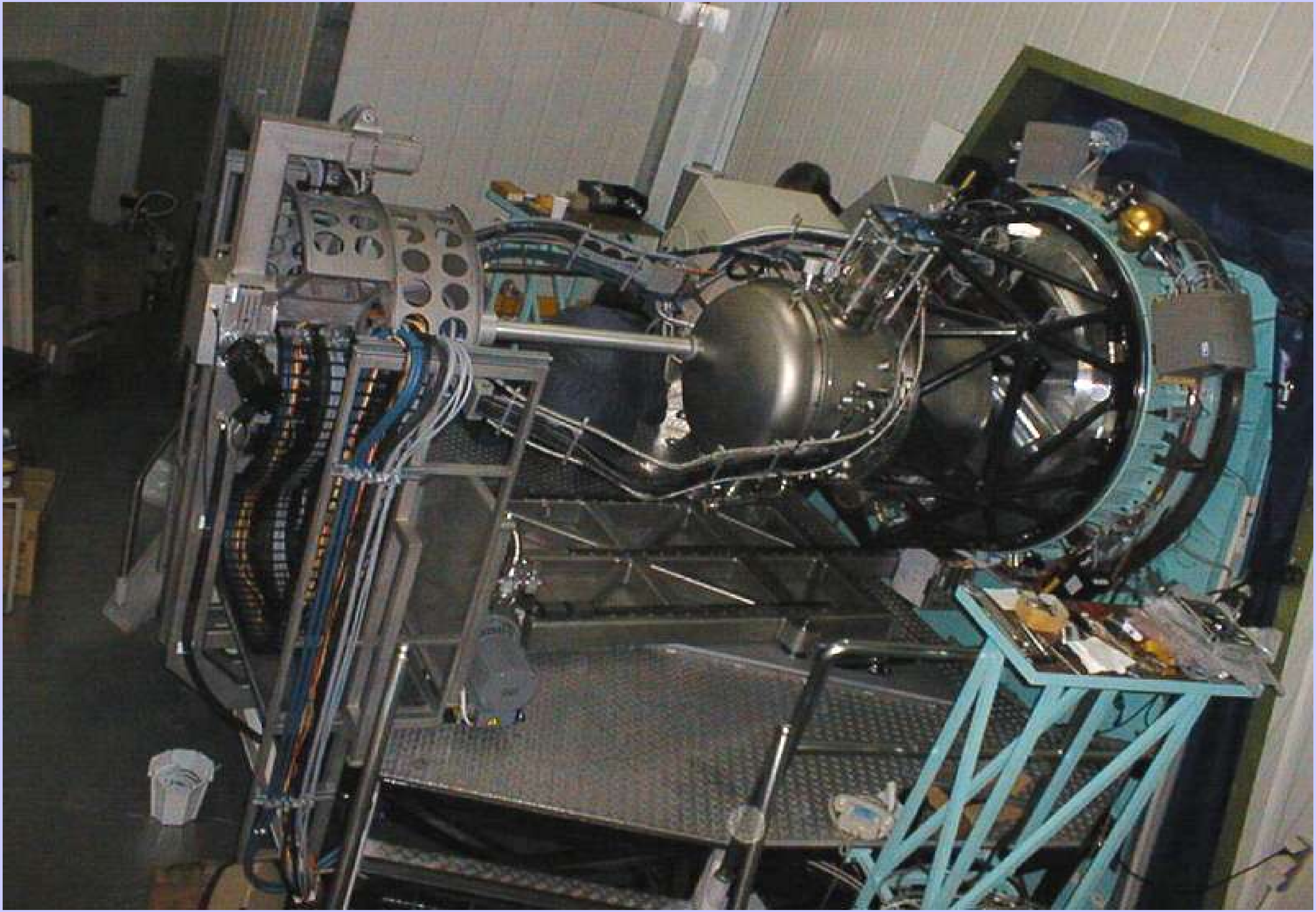
$$(440\ \ arcmin^{2})\ ,\ (K_{s}<19.2)$$

New Technology Telescope (NTT)

Close view of NTT

- **Location :** **70° 43' 54.272" W**
  -29° 15' 18.440" S
- **Altitude :** **2375 m**
- **Diameter :** **3.58 m**

SOFI camera :



Subaru Telescope enclosure

- Altitude: 4139 m
- Latitude: 19d 49m 43s N
- Longitude: 155d 28m 50s W
- Height: 43 m
- Diameter at base: 40 m
- Weight: 2000t
- Outer wall: aluminum panels

Subaru Telescope

Primary mirror

- Effective diameter : 8.2 m
- Thickness: 20 cm
- Weight: 22.8 t
- Material: ULE (ultra-low thermal expansion glass)
- Mean Surface error: 14 nm
- Focal length: 15 m

Telescope structure

N-IR imaging & Data reduction

Deep3a-F

- ESO science archive : **NTT** **J & Ks** band images
- NTT + SOFI (1K× 1K) , 0."29 / pixel , 4.9′ × 4.9′
- Deep3a-F : a part of ESO Deep Public Survey (DPS) by ESO Imaging Survey (EIS)
- ~ 920 arc min² (K ~19-19.5) & ~ 320 arc min² (K≥ 20 & J ≥22)
- Reduction : EIS/MVM pipeline

Daddi-F

- Daddi et al 2000 reduced **NTT** **K**-band + William Herschel Telescope (WHT) **R**-band data

Optical imaging & Data reduction

- Subaru + Suprime-cam (ten 2k × 4k CCDs, 37′× 27′, 0."202 /pixel)
- Deep3a-F : B, R , I & Z (2003 March 4-5) with 0".7-0".9 seeing
- Daddi-F : B, I & Z (2003 March 4-5)
- SA95 : B , R & I band flux calibration
- SA95-190 & SA95-193 : Z band flux calibration
- Reduction : pipeline Suprime-cam Deep Field REDuction (SDFRED) package

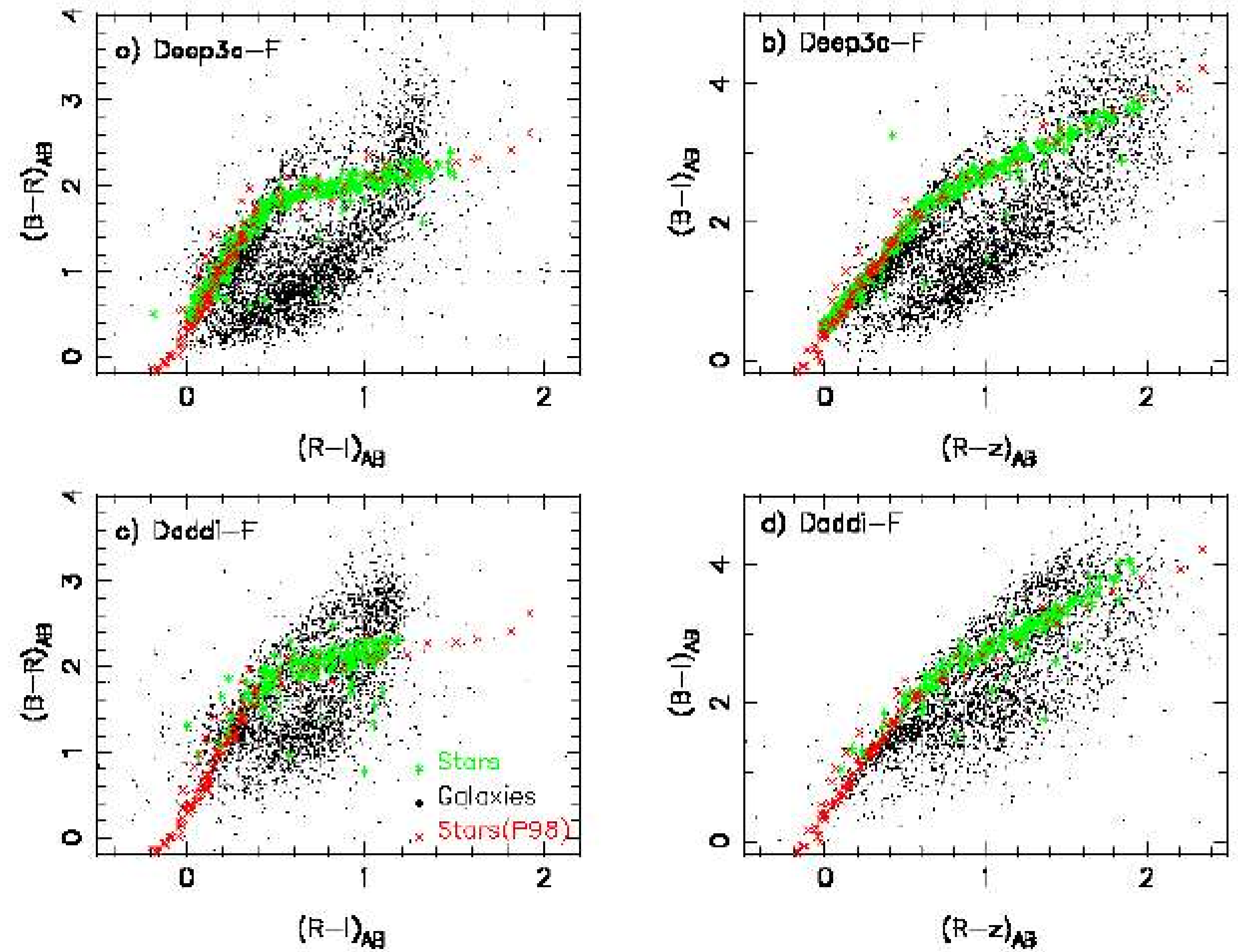
photometry

- Deep3a-F
- Source detection : Sextractor
- Galactic extinction : $A_B = 0.18$ (Schlegel et al. 1998)

- Daddi-F
- The sample of K selected galaxies in Daddi et al. 2000
- Galactic extinction : $A_B = 0.13$ (Schlegel et al. 1998)

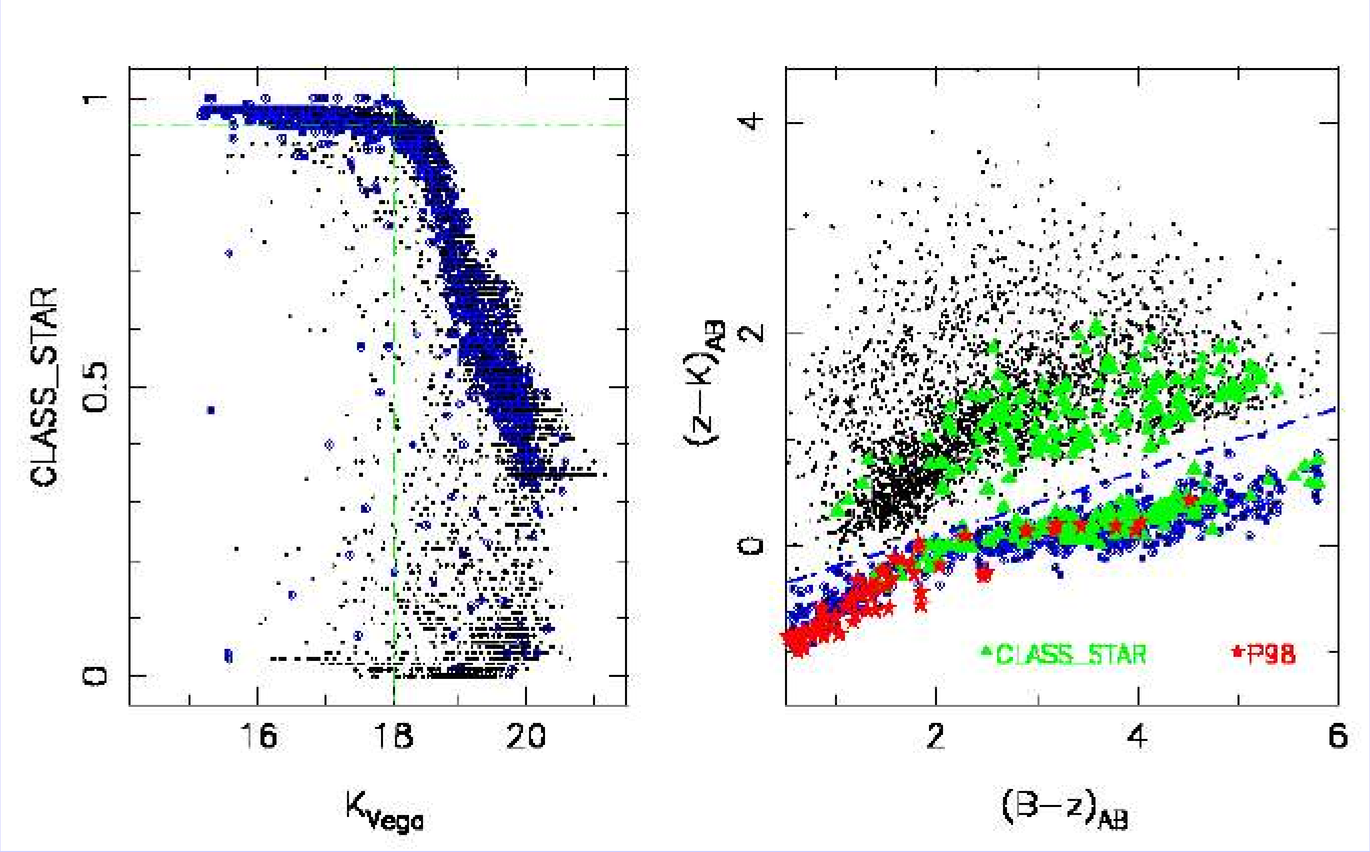
- Star-galaxy separation
- Color criterion : $(z - K)_{AB} < 0.3(B\text{-}z)_{AB} - 0.5$
- CLASS_STAR : the shape of the objects profile
- The color classification is superior
- Allowing to reliably classify stars up to the faintest limits in the survey

photometry



a) Deep3a–F
b) Deep3a–F
c) Daddi–F
d) Daddi–F
$(B-R)_{AB}$
$(B-I)_{AB}$
$(R-I)_{AB}$
$(R-z)_{AB}$
Stars
Galaxies
Stars(P98)

photometry



Selection of EROs & BzKs:

- *I* : EROs
- ***II*** **:** star-forming galaxies (SBzKs), Daddi et al- 2004a
- ***III*** **:** passively evolving galaxies (PBzKs) Daddi et- al 2004a

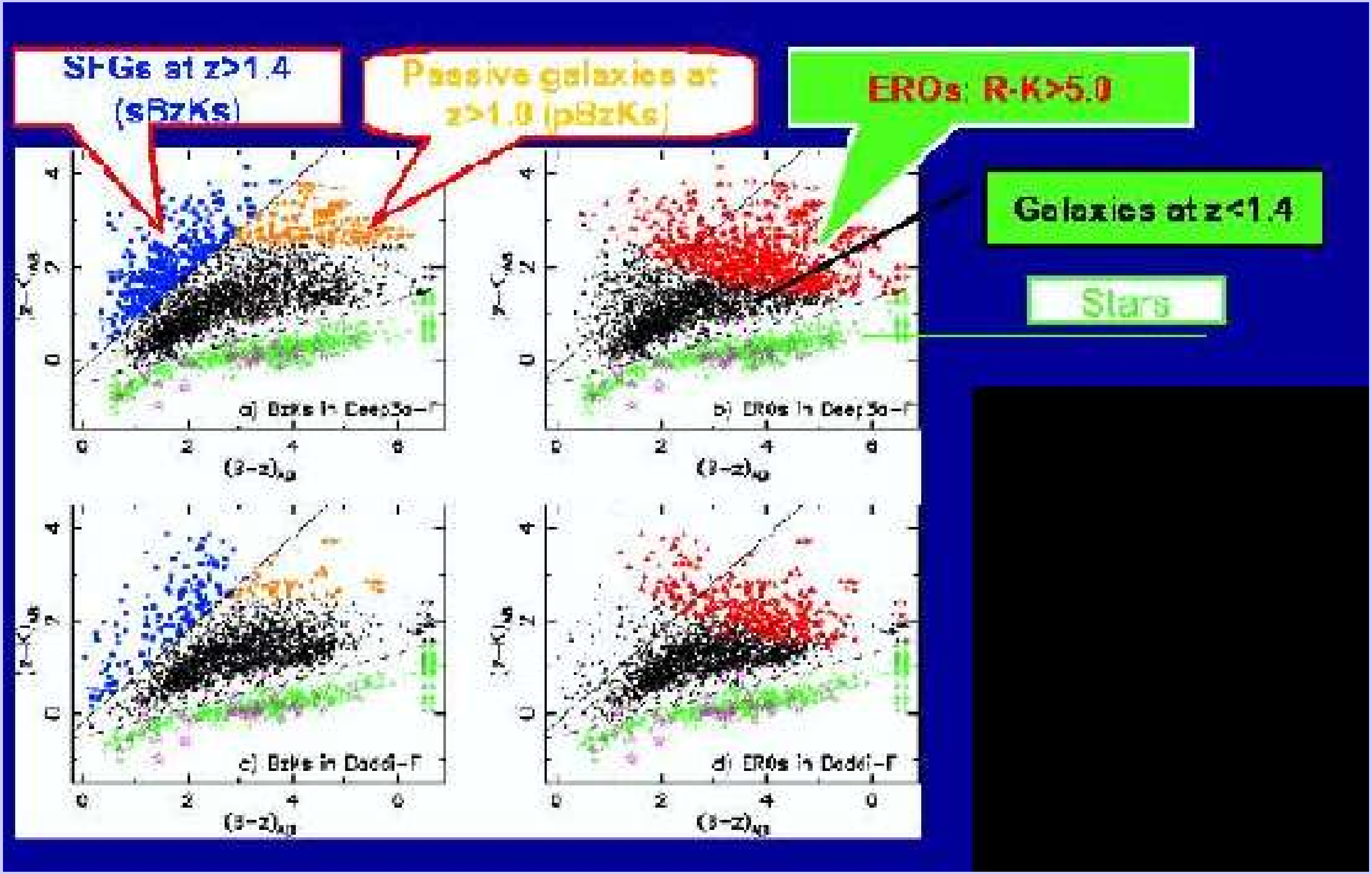
$$R_{Subaru} - K > 3.7\ (Deep3a{-}F) \quad (I)$$
$$R_{WHT} - K > 3.35\ (Daddi{-}F) \quad (I)$$

$$BzK = (z - K)_{AB} - (B - z)_{AB} \quad ,\ 1.4 < z < 2.5$$

$$BzK > -0.2\ (II)$$

$$BzK < -0.2,\ (z - K)_{AB} > 2.5\ (III)$$

Selection of EROs & BzKs :



Surface density

- **sBzKs**
  - Kong et al. 2005 : $1.2 \pm 0.05\, arcmin^{-2}, \;\; K_{vega} \leq 20$
  - K20 field (Daddi et al 2004a): $0.91 \pm 0.13\, arcmin^{-2}$
  - GOODS North field (Daddi et al 2005b) : $1.0 \pm 0.08\, arcmin^{-2}$

- **pBzKs**
  - Kong et al. 2005 : $0.38 \pm 0.03\, arcmin^{-2}, \;\; K_{vega} \leq 20$
  - This result is slightly larger than the others
  - This might be the result of strong clustering and lower overall surface density

- Density of sBzKs & pBzKs in Daddi-F is consistent with that in Deep3a if limited at $K_{vega} \leq 19$

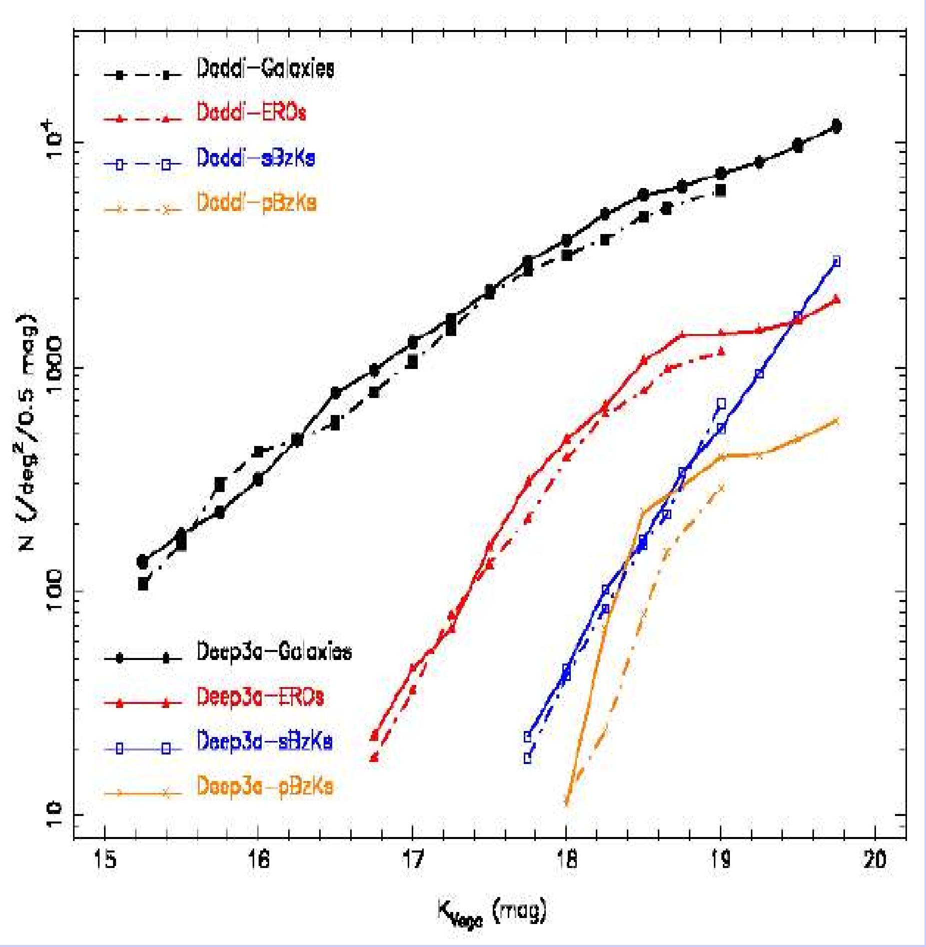
Selection of EROs :

- 90 of EROs are also sBzKs (in Deep3a-F)
- 121 EROs are pBzKs

Result :

- 41% of EROs are selected by BzKs. (Kong et al. 2005)
- They are in the high-z tail($z > 1.4$ for $K < 20$)
- Daddi et al. 2004A (35 %)
- Moustakas et al. 2004 for full GOODS-South area (similar)
- In Daddi-F 29% of EROs at $K < 19.2$ are in high tail redshift(Kong et al. 2005)

Number counts



- For all high-Z galaxies $(K \geq 17)$
- The slope of the counts are steeper
- The fraction of sBzKs in the Deep3a-F increases very steeply
- Counts of sBzKs in Daddi-F are identical to that in Deep3a-F.
- In EROs it ***"flattens out"*** toward faint magnitudes
- In EROs a ***break*** in K~18 is very similar to McCarthy et al. 2001 and smith et al. 2002

Number counts

- The break for pBzKs is shifted to z ~ 1-1.5 mag. fainter
- EROs & pBzKs have fairly ***narrow*** redshift distributions
- For EROs the peak of redshift distribution is in z ~ 1 (Cimatti et al 2002b ; Yan et al. 2004 ; Doherty et al. 2005)
- For pBzKs the peak is in z ~ 1.7 (Daddi et al. 2004b;2005a)
- **"Number counts"** might be direct probes of **"LF"**.
- The shift in the counts is consistent with the different typical red-shift of two population
- For sBzKs the slope is roughly constant
- Much wider Z-distribution

Kong et al. 2005

Surface density

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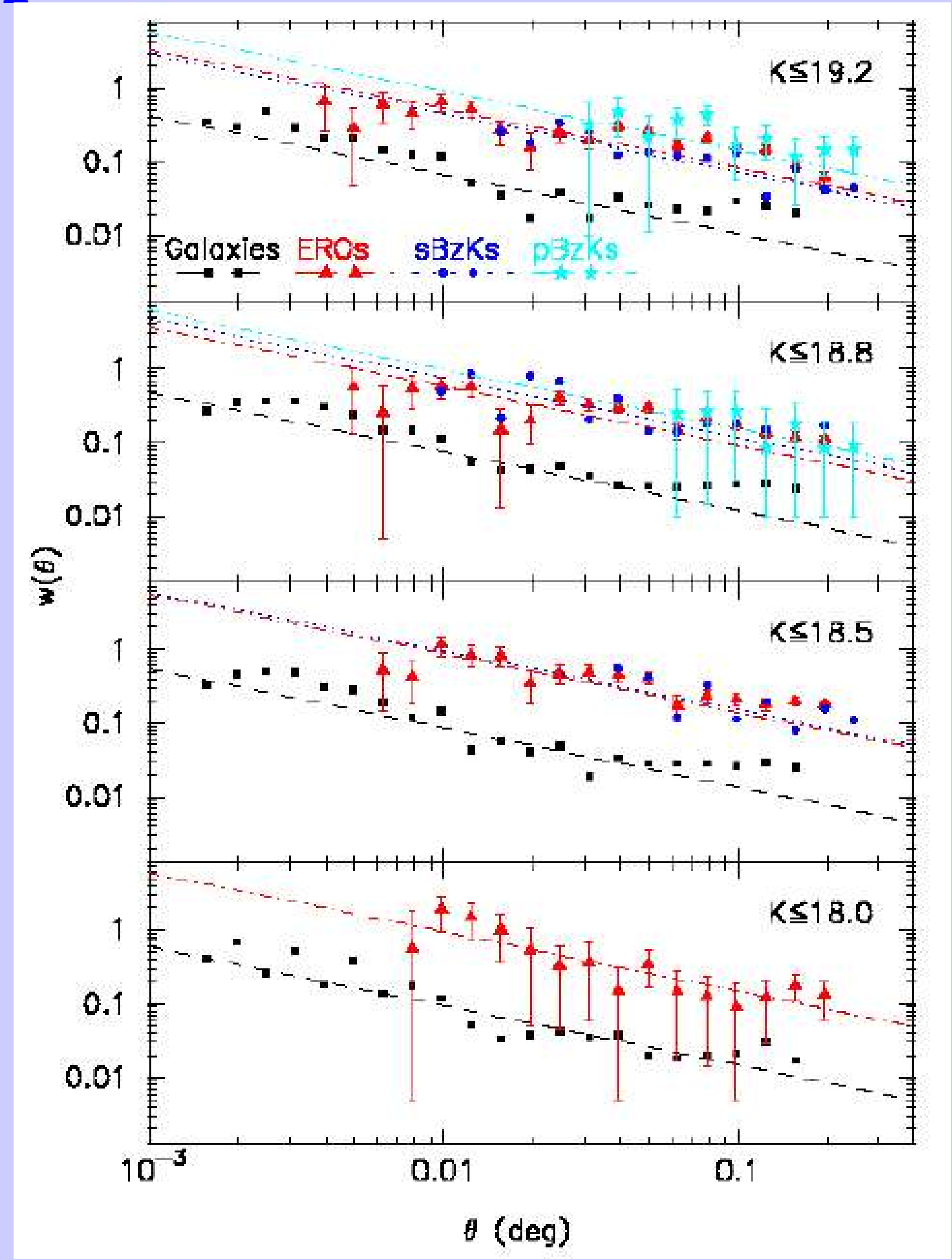
Clustering properties in Daddi-F



- Landy & Szalsy (1993)

$$w(\theta)=\frac{(DD-2DR+RR)}{RR}=A\theta^{-\delta};\delta=0.8$$

EROs & BzKs

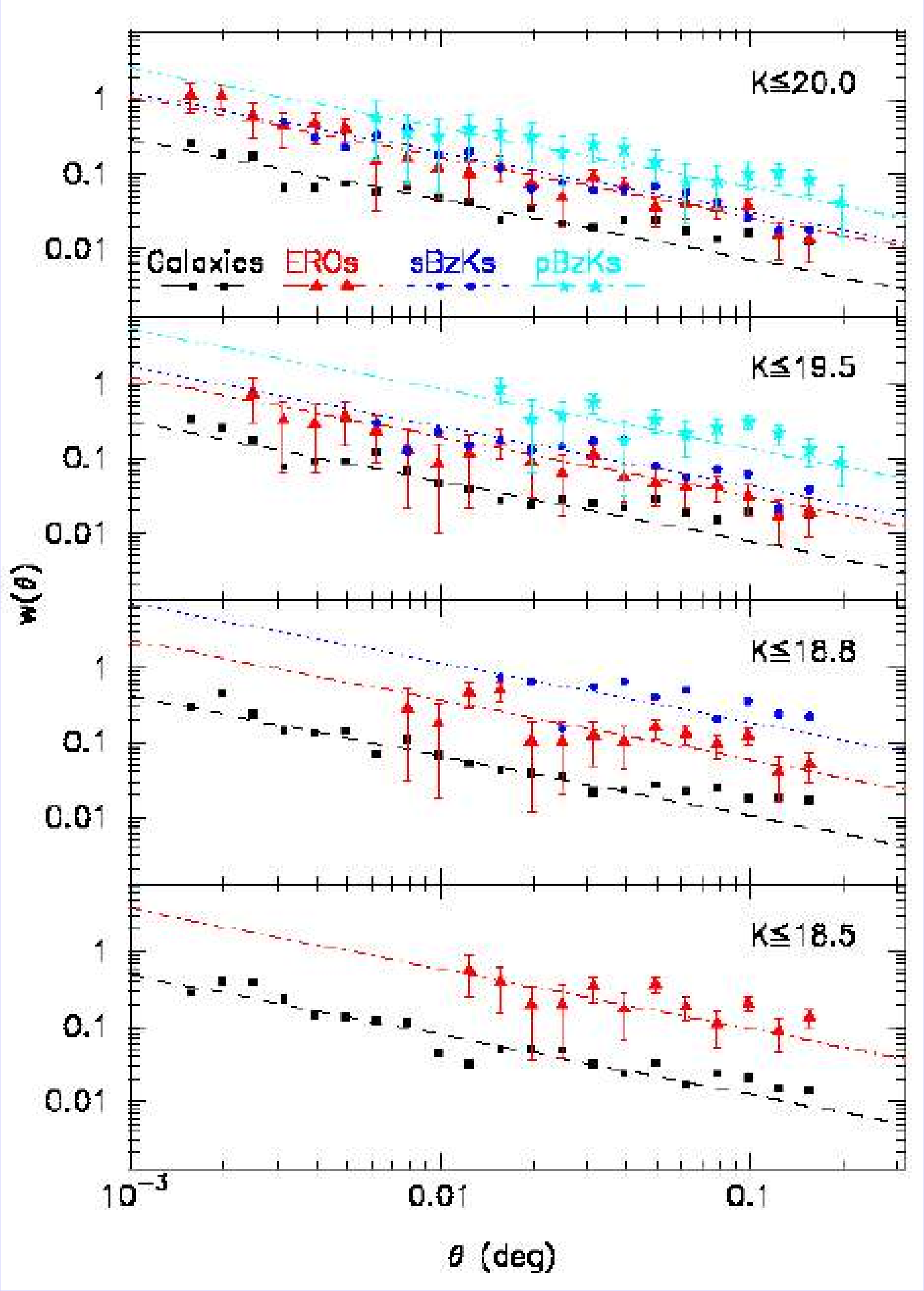
- K fainter, A decrease
- sBzKs are strongly clustered as EROs:

et al. 2004 (9 sBzKs)

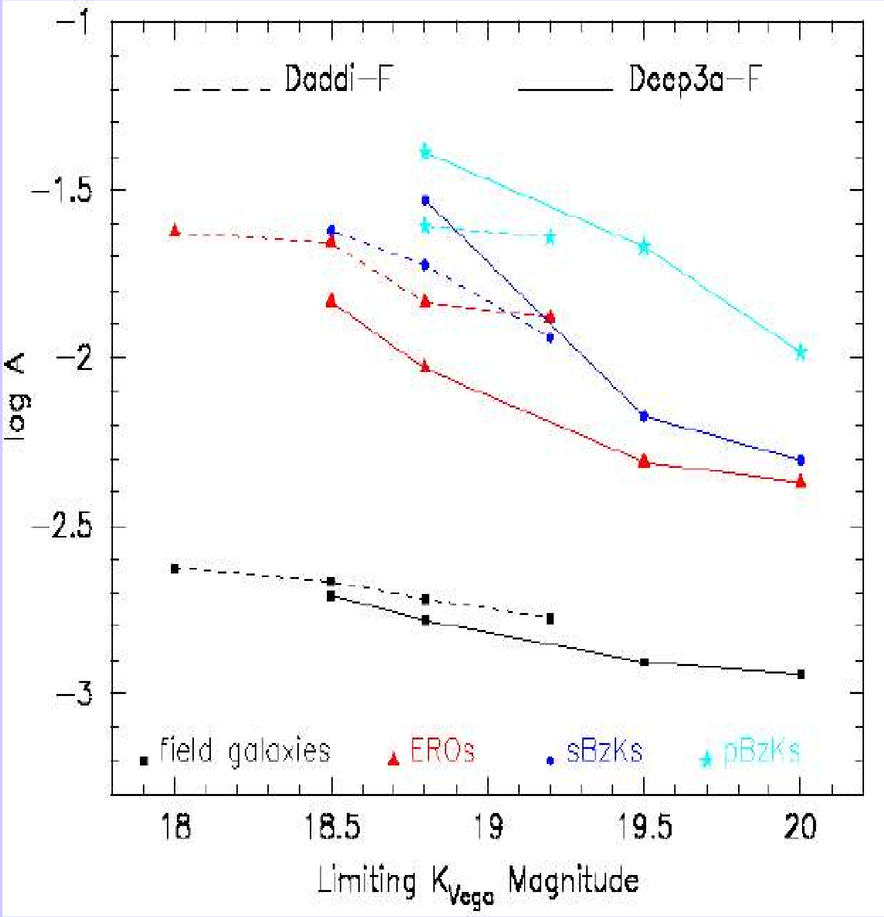
2005 (500 sBzKs)

- pBzKs are the most strongly clustering

Clustering properties in Deep3a-F



Angular clustering magnitudes



- Fainter galaxies, lower clustering
- Fainter K objects are less massive or have wider Z-distribution or both.
- PbzKs : 1.4 < Z < 2 : strong clustering

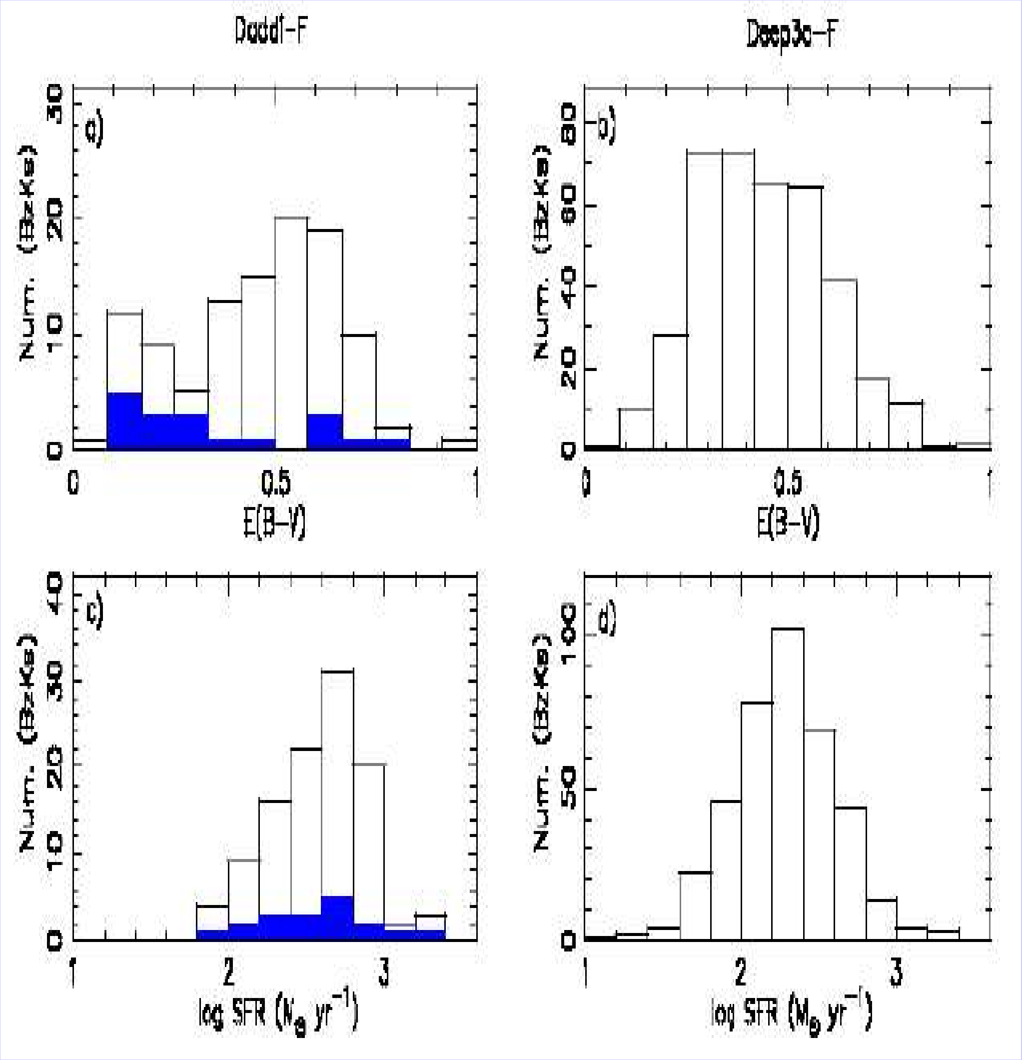
Properties of sBzKs

- **Reddening E(B – V) estimation from B – Z , providing a measure of the UV slope (Daddi et al 2004a)**
- **Reddening corrected B flux(ave. z = 1.9)**
- **BC03**
- **Estimation of 1500A° rest frame luminosity**

Result

- ***SFR* [consistent with radio & far-IR based estimation (Daddi et al. 2005b)]**

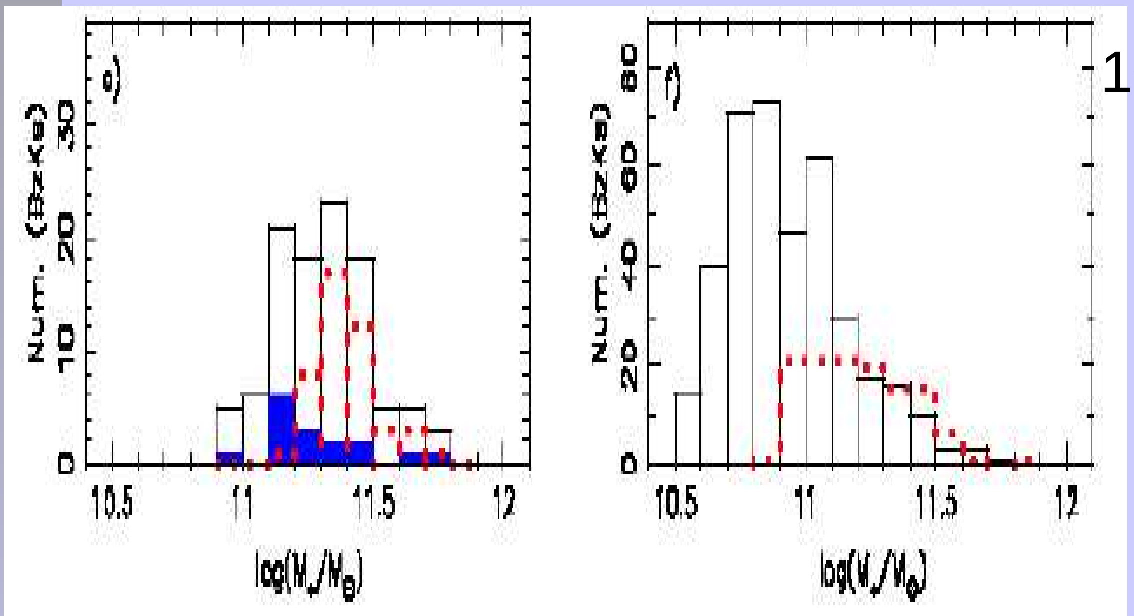
Reddening & SFR



- **Daddi-F (K < 19.2)**
  - **95 % , have SFR > 70**
  - **Median of SFR is 370**
- **Deep3a-F (K < 20)**
  - **90 % have SFR > 70**
  - **Median of SFR is 190**
  - **E(B – V) = 0.44**
  - **55 % have E(B-V) > 0.4**

Stellar masses of BzKs

Daddi-F **Deep3a-F**



Daddi-F

- ~ 95 % of sBzKs : M > 10^{11} M_{sun}

$$sBzKs \;\; ; \;\; \bar{M} = 2 \times 10^{11} M_{sun}$$

$$pBzKs \;\; ; \;\; \bar{M} = 2.5 \times 10^{11} M_{sun}$$

Deep3a-F

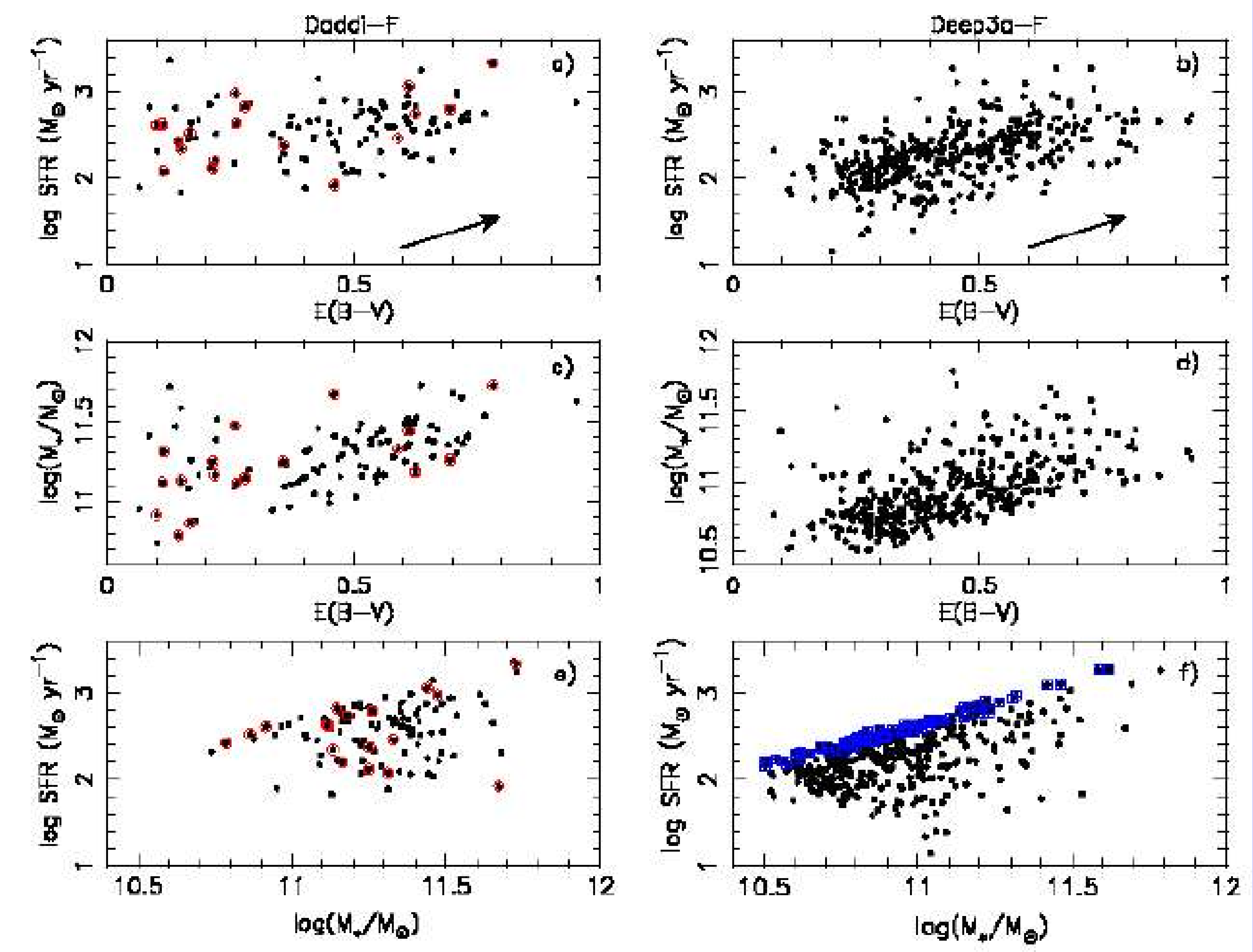
- ~ 40 % of sBzKs: M > 10^{11} M_{sun}

$$sBzKs \;\; ; \;\; \bar{M} = 8.7 \times 10^{10} M_{sun}$$

$$pBzKs \;\; ; \;\; \bar{M} = 1.6 \times 10^{11} M_{sun}$$

"Difference is due two different K-limiting mag."

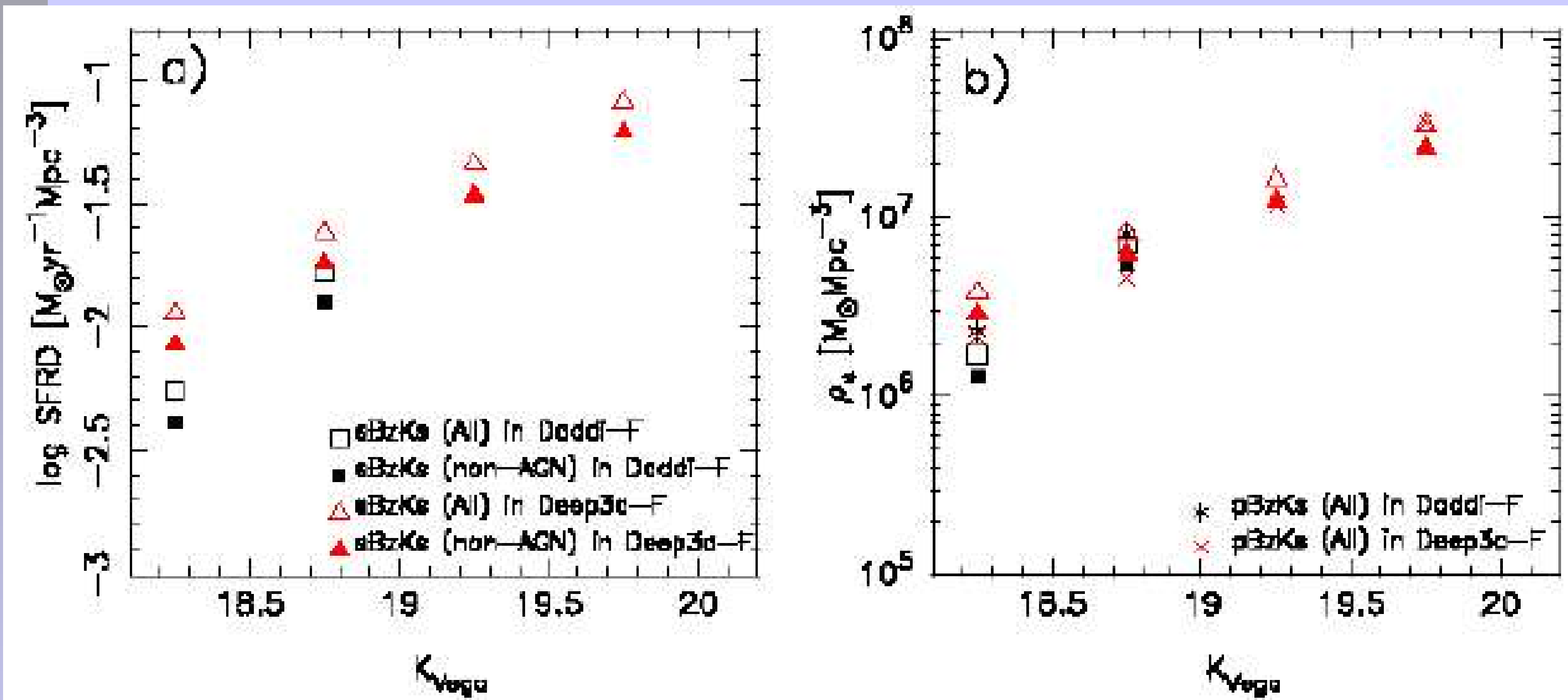
Correlation between physical quantities



Correlation between physical quantities

- SFR & Reddening for z ~2 galaxies
  - ***High SFR more obscuration***
  - local universe (Calzetti 2004)
  - z~3 LBGs
- E(B-V) *& Stellar Mass*
  - **More massive galaxies are more absorbed**
- *SFR & Stellar mass*
  - **A limit on the max. SFR in a galaxy of a given mass**
  - **Most massive sBzKs are most actively SF**

Mass & SFRDs



Kong et al. 2005

Conclusion

- The log of the number counts of sBzKs increases linearly But for pBzKs it ***flattens out*** by K ~ 19

- The selected sBzKs & pBzKs are a factor of 10 more than K20 survey

→ ~ 30% higher surface density

- Clustering of EROs and BzKs are very similar (~10 times higher than generic galaxies)

- The strong clustering of EROs and BzKs makes a reasonable evolutionary link between EROs at z ~ 1 and BzKs at z ~ 2

- Subsiding of SFR in sBzKs by $z \sim 1$ produces passively-

Conclusion

- High SFR & mass of sBzKs at z ~2 : $10^{11} M_{sun}$
- ➜ sBzKs are among the precursors of z ~ 1 passive EROs and z ~ 0 early-type galaxies
- The contribution of sBzKs to SFRD (~0.06 $M_{sun}\ yr^{-1}\ Mpc^{-3}$) is comparable to the global SFRD at Z ~2 from simulations or other surveys
- The number density of sBzKs is very close to pBzKs (at Z~2)
- The number density of massive pKzBs is about 45 % of the early type galaxies at z = 0.

Result:

➜ Quenching of SF. Doubles the number of massive , passively evolving galaxies since < z > ~ 1.7

Special thanks to your attention