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# Old galaxies at z > 1

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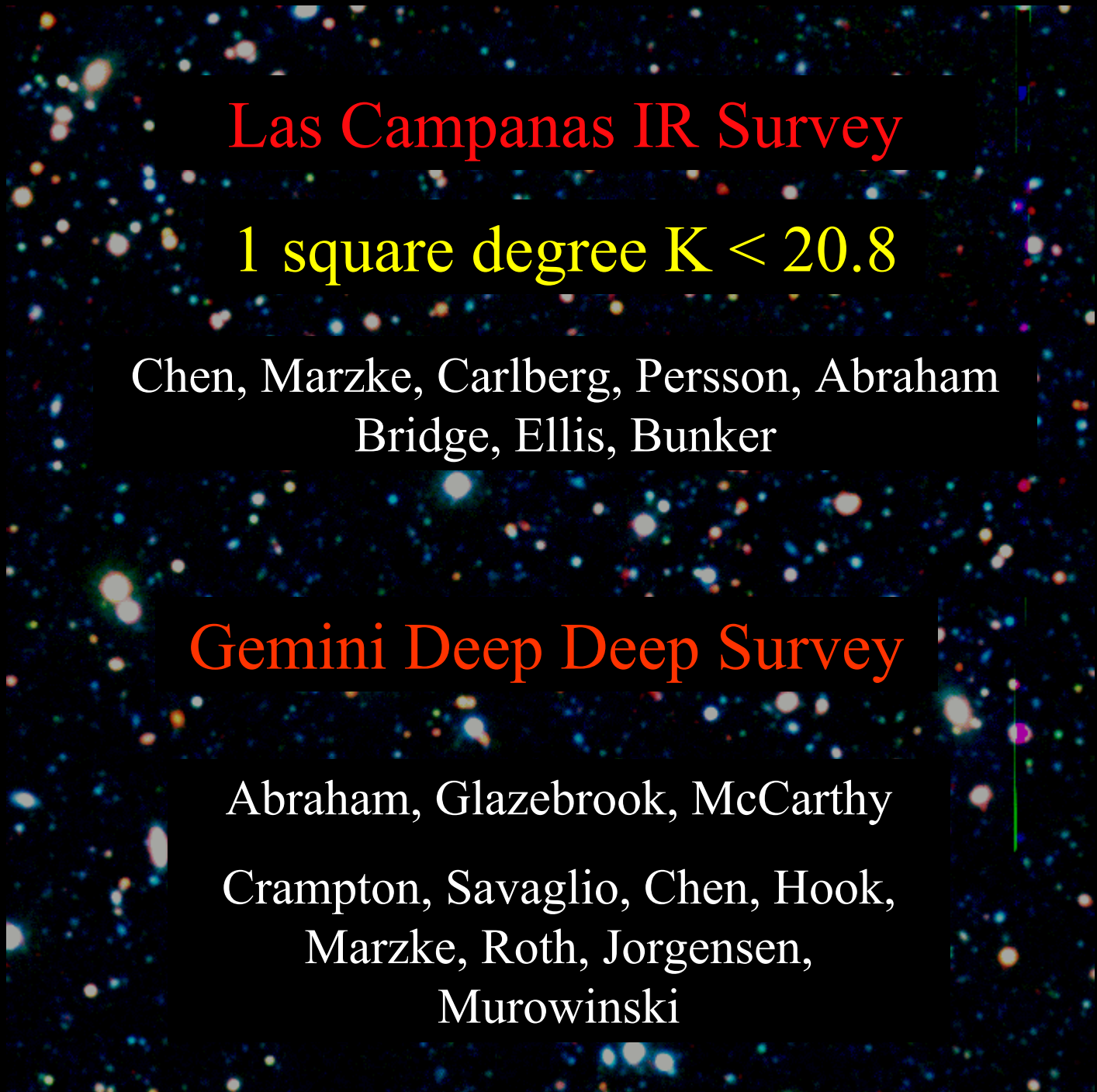
Old Galaxies at z > 1
P. J. McCarthy
Carnegie
Observatories
ETH
Conference
Aug 21, 2003


Las Campanas IR Survey
1 square degree K < 20.8
Chen, Marzke, Carlberg, Persson, Abraham
Bridge, Ellis, Bunker
Gemini Deep Deep Survey
Abraham, Glazebrook, McCarthy
Crampton, Savaglio, Chen, Hook,
Marzke, Roth, Jorgensen,
Murowinski

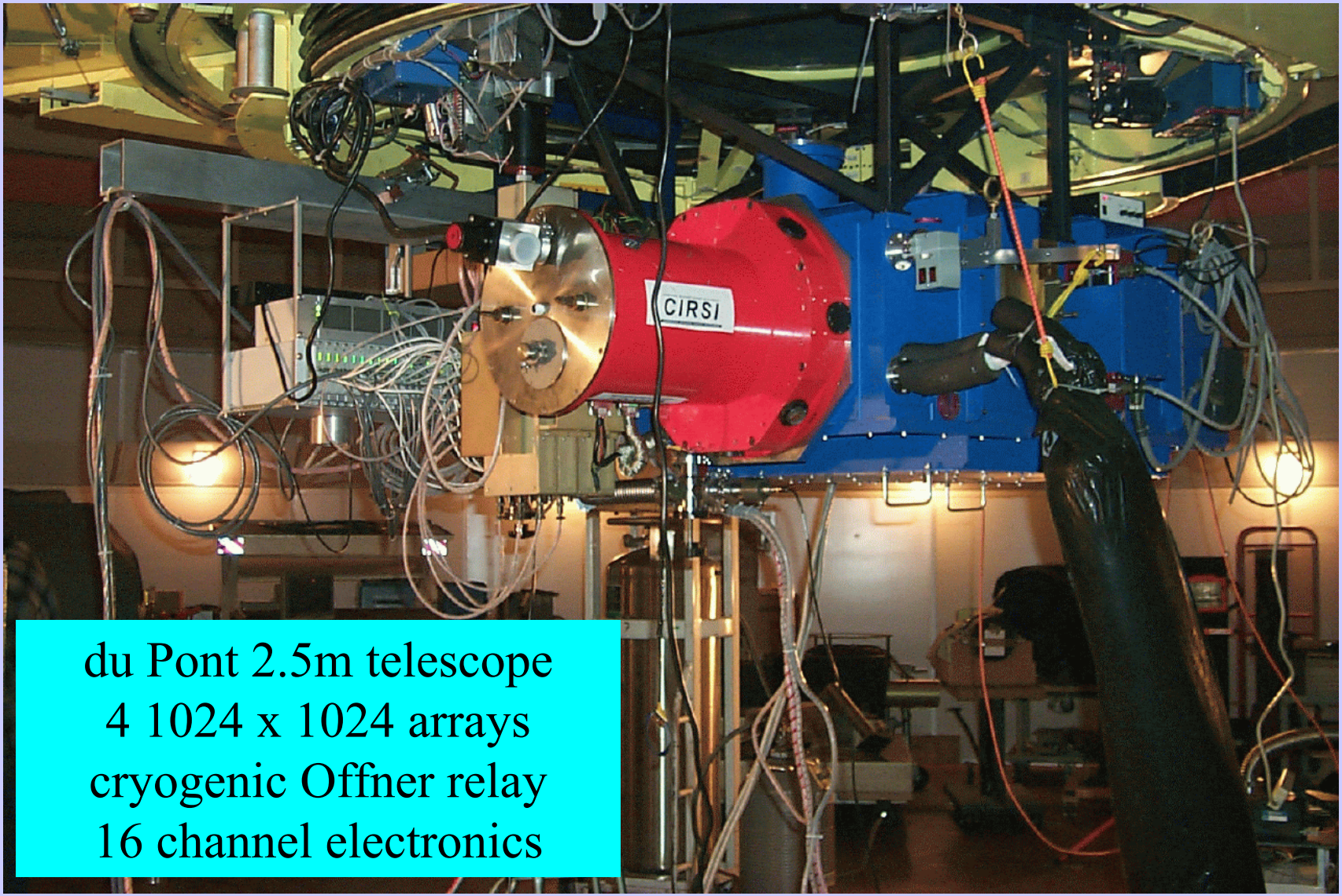
# GOALS

- Galaxy Assembly in the $1 < z < 2$ Epoch
- Space density of massive galaxies
- Stellar evolution in early type galaxies
- Evolution of 3-D Clustering

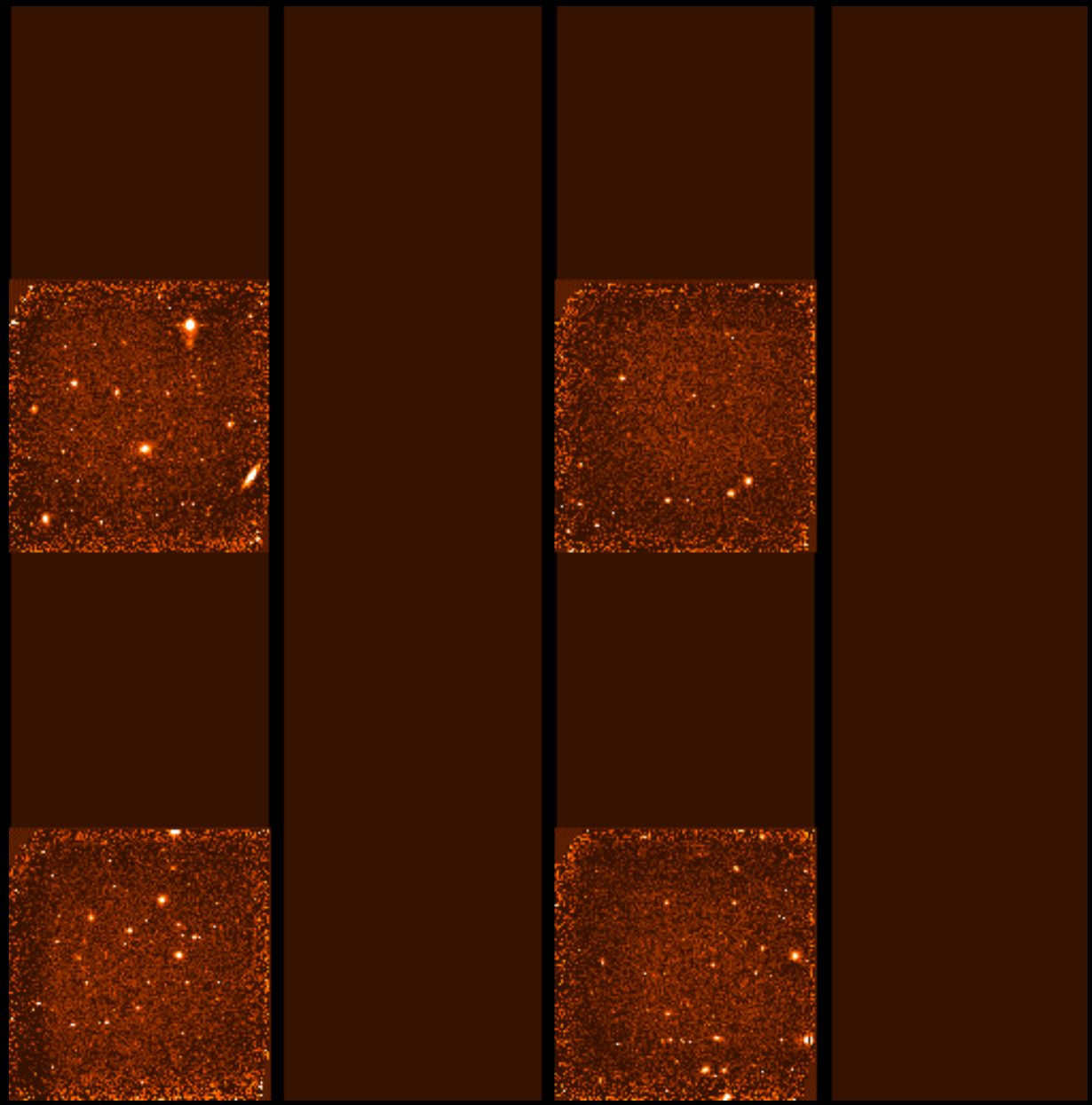
# Approach

- Multi-color optical & near-IR imaging survey
- Depths keyed to $z = 2$ elliptical: Ks ~ 21 !
- Photometric & spectroscopic redshifts
- Six fields – 1 square degree total area

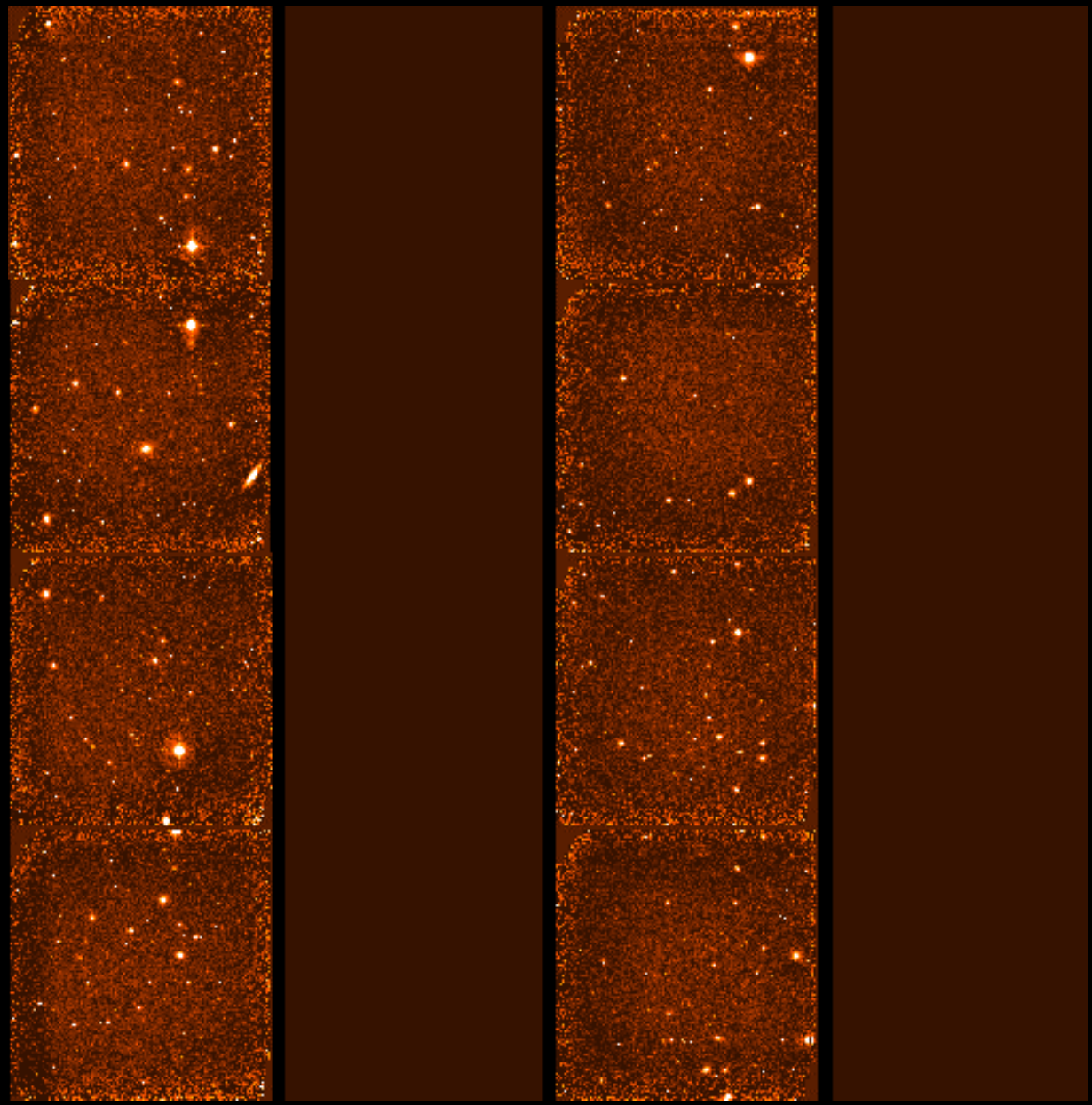
# CIRSI + LCO Wide Field IR Camera



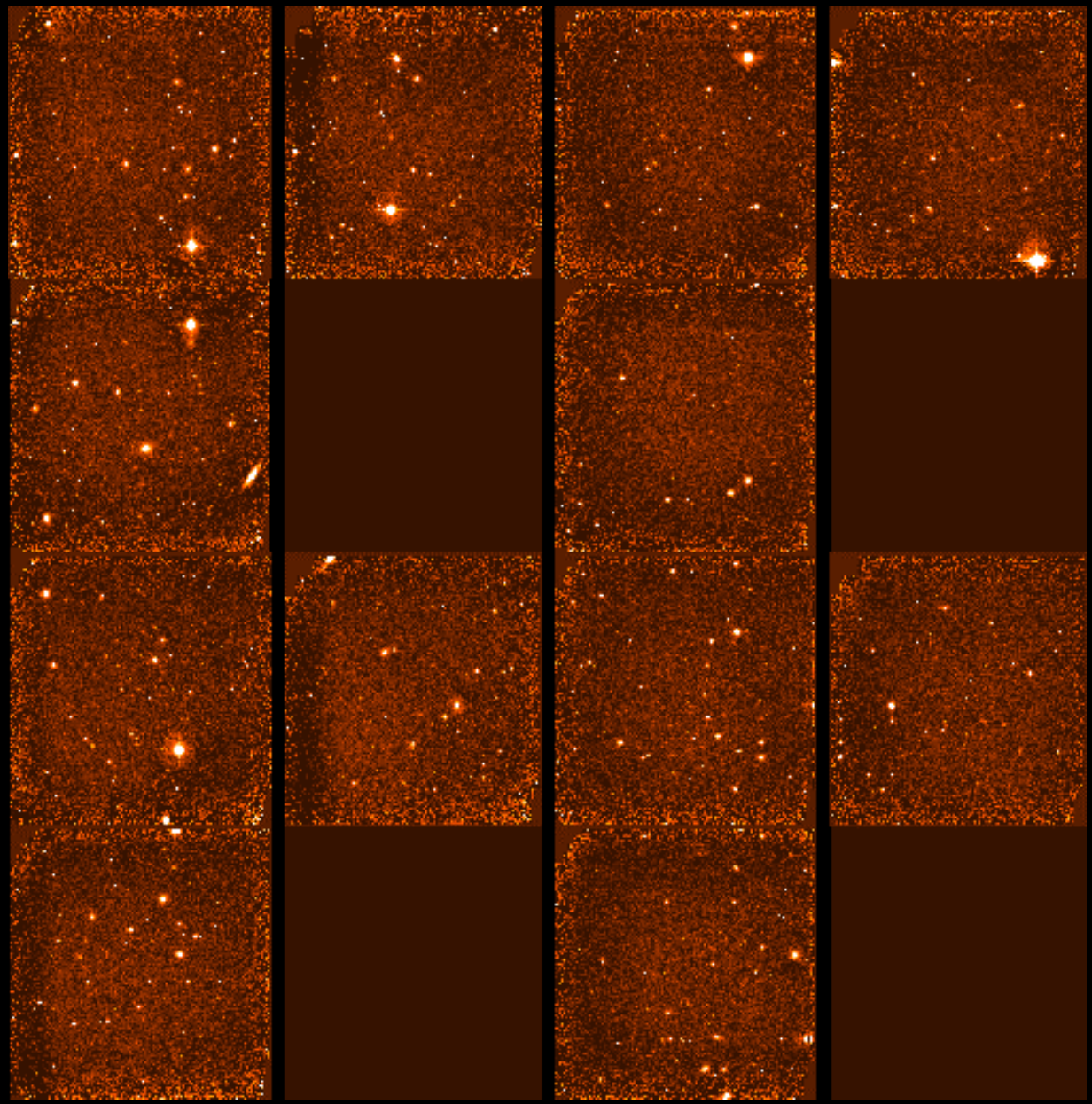

du Pont 2.5m telescope
4 1024 x 1024 arrays
cryogenic Offner relay
16 channel electronics



4 1024x1024 detectors – 90% gaps



4 pointings – 16 1024 x 1024 images



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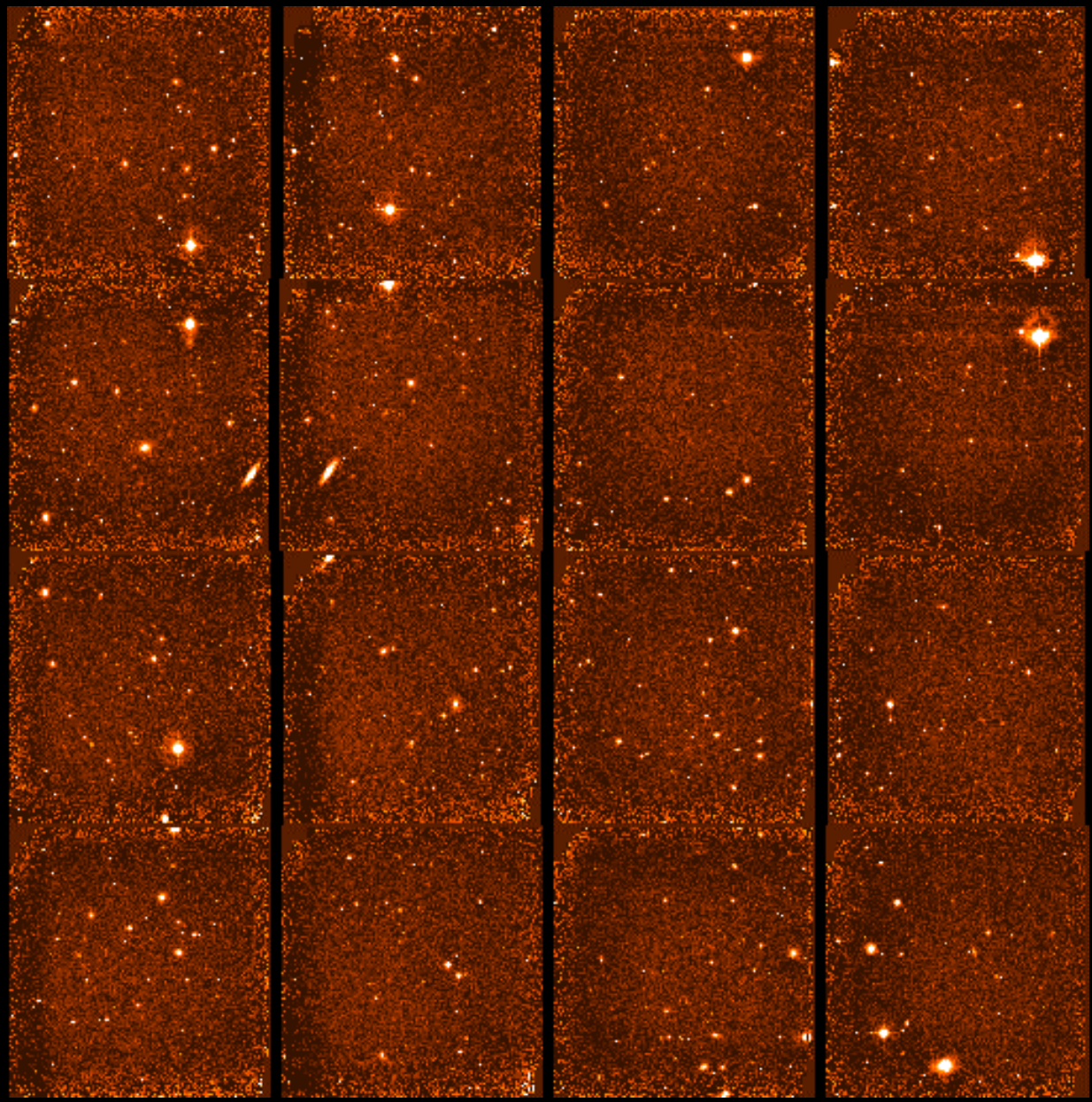
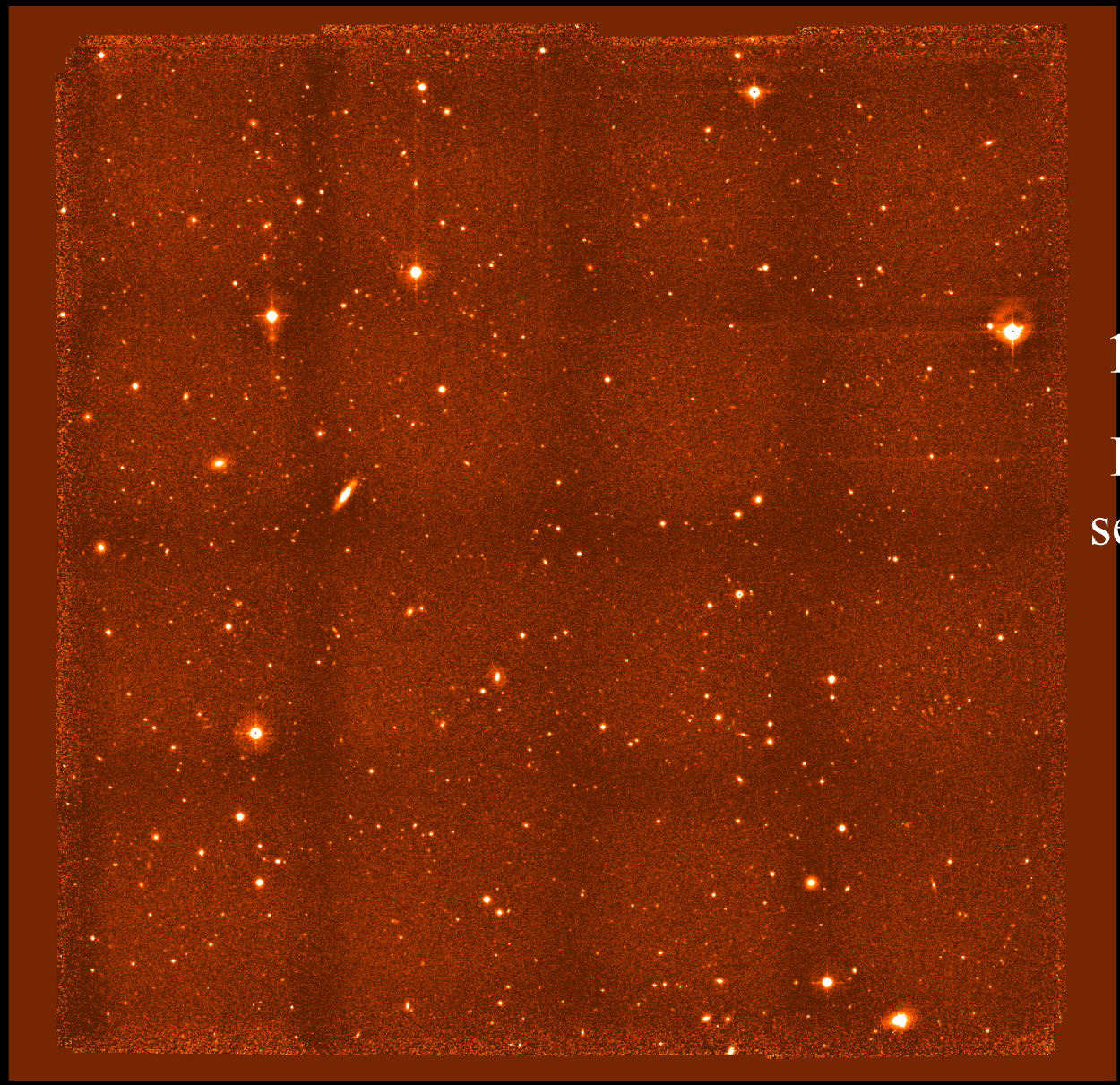


4 pointings – 16 1024 x 1024 images



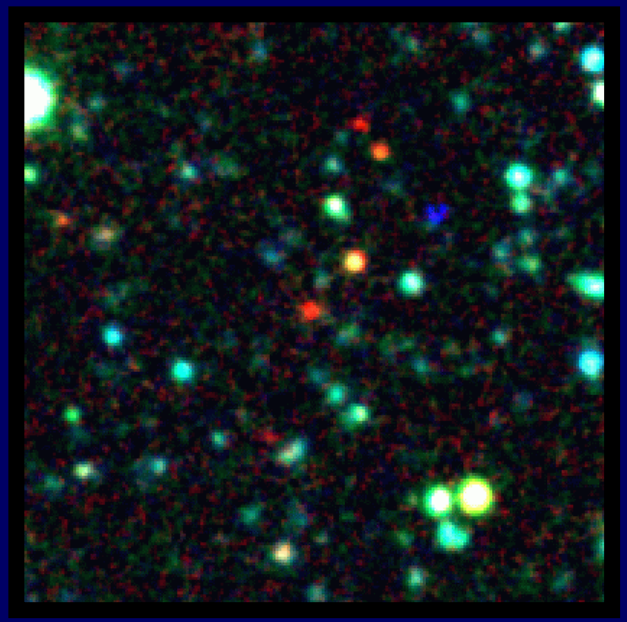
100,000

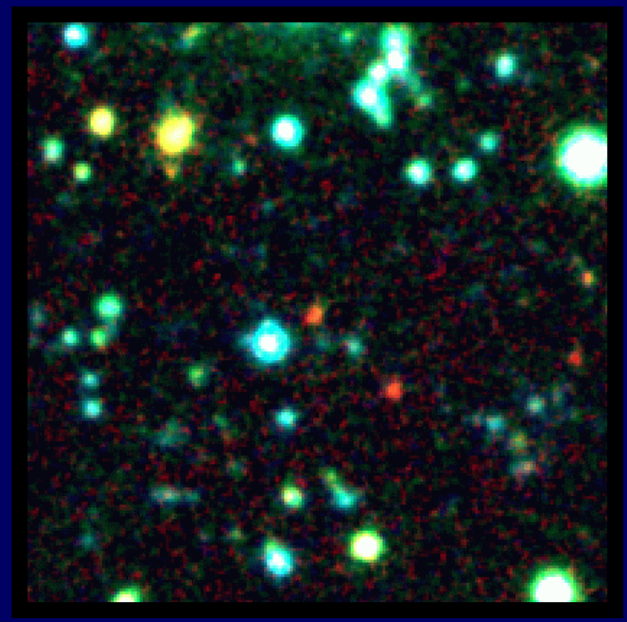
1024 x 1024

Frames - 30 seconds each

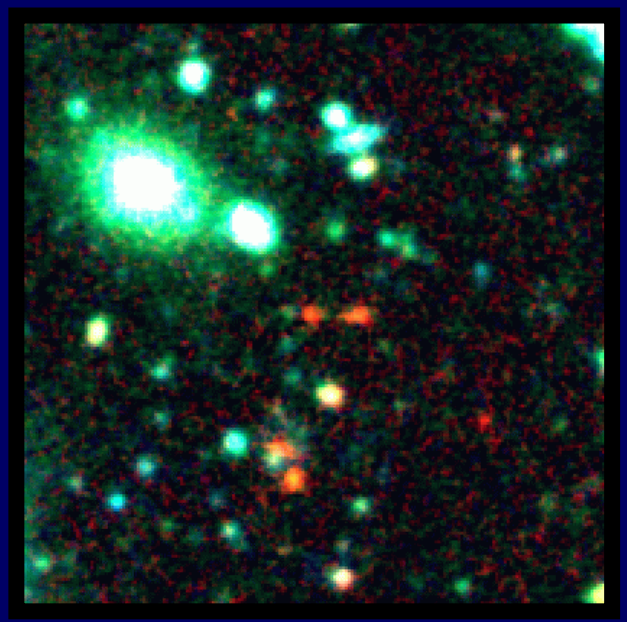
13’ x 13’ mosaic – 3 hour exposure

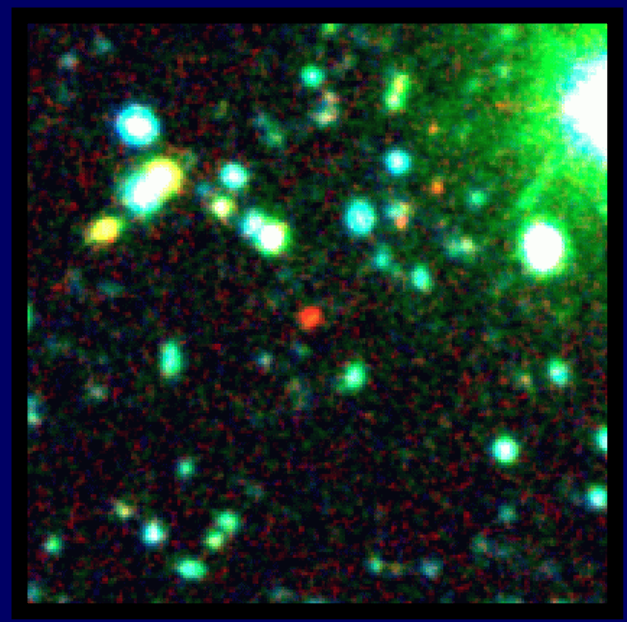
# Red Galaxies are Abundant





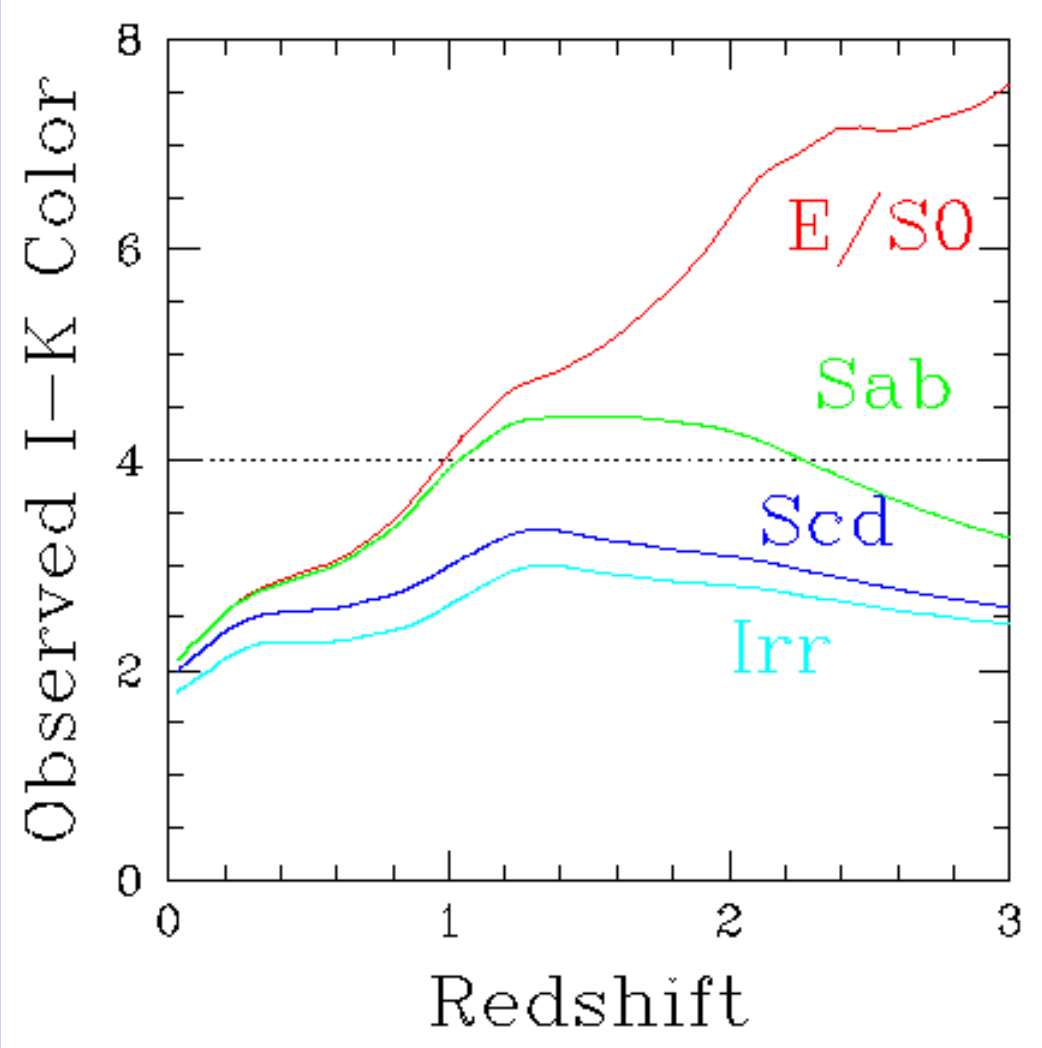
V,I,K





80”

# IR - Optical Color Selection

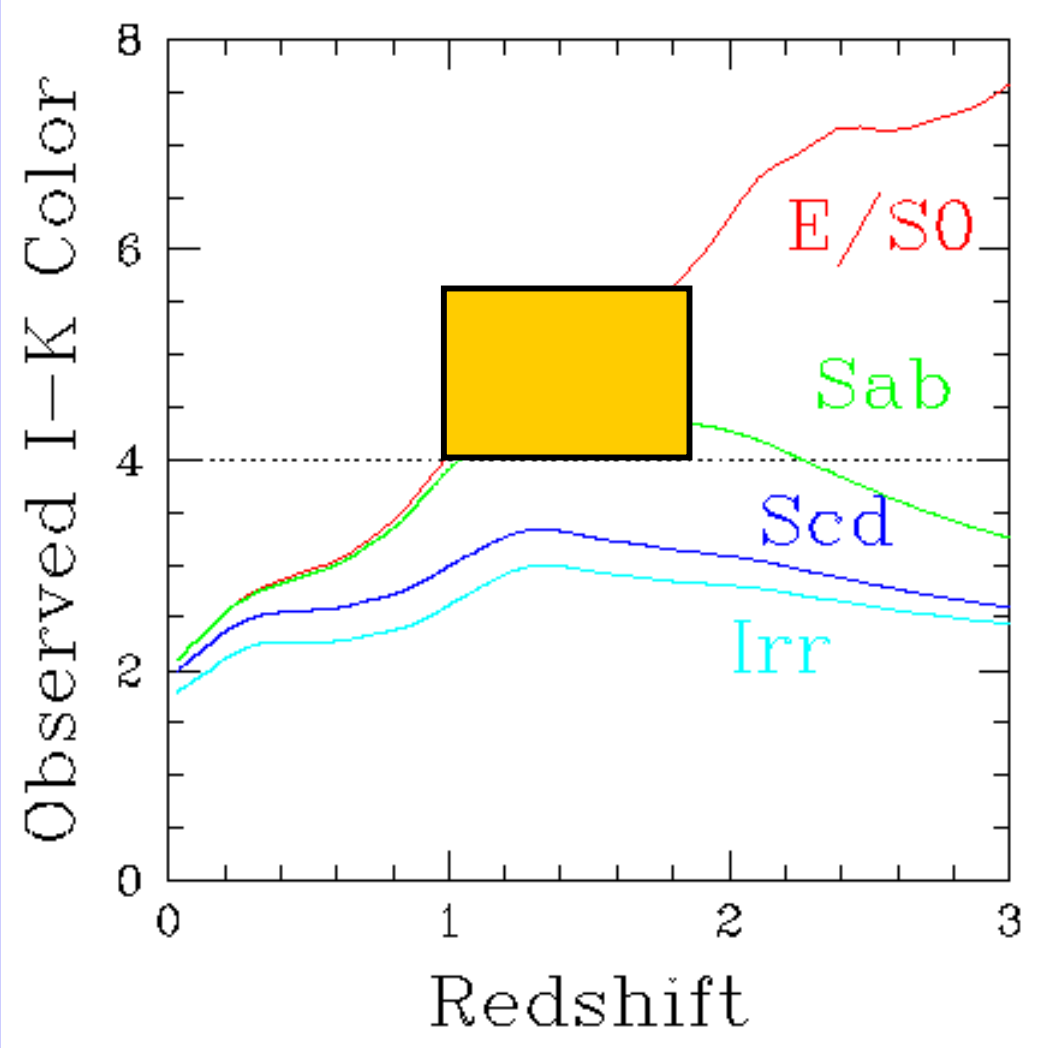



I-K > 4

Rejects z < 1

Foreground & late types at all redshifts

# IR - Optical Color Selection

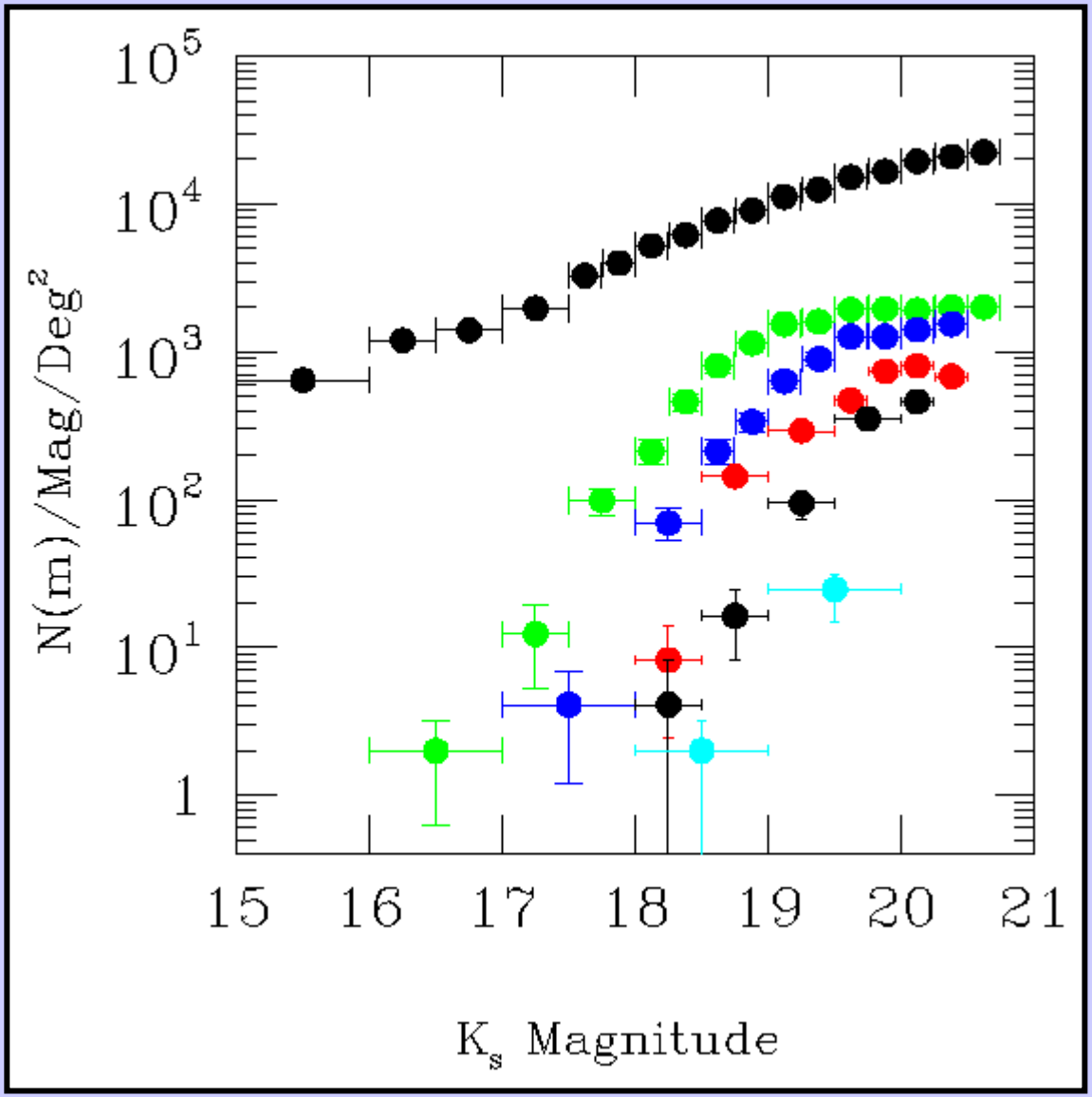



I-K > 4

Rejects z < 1

Foreground & late types at all redshifts

# Number-Magnitude Relations




I-K > 3.5

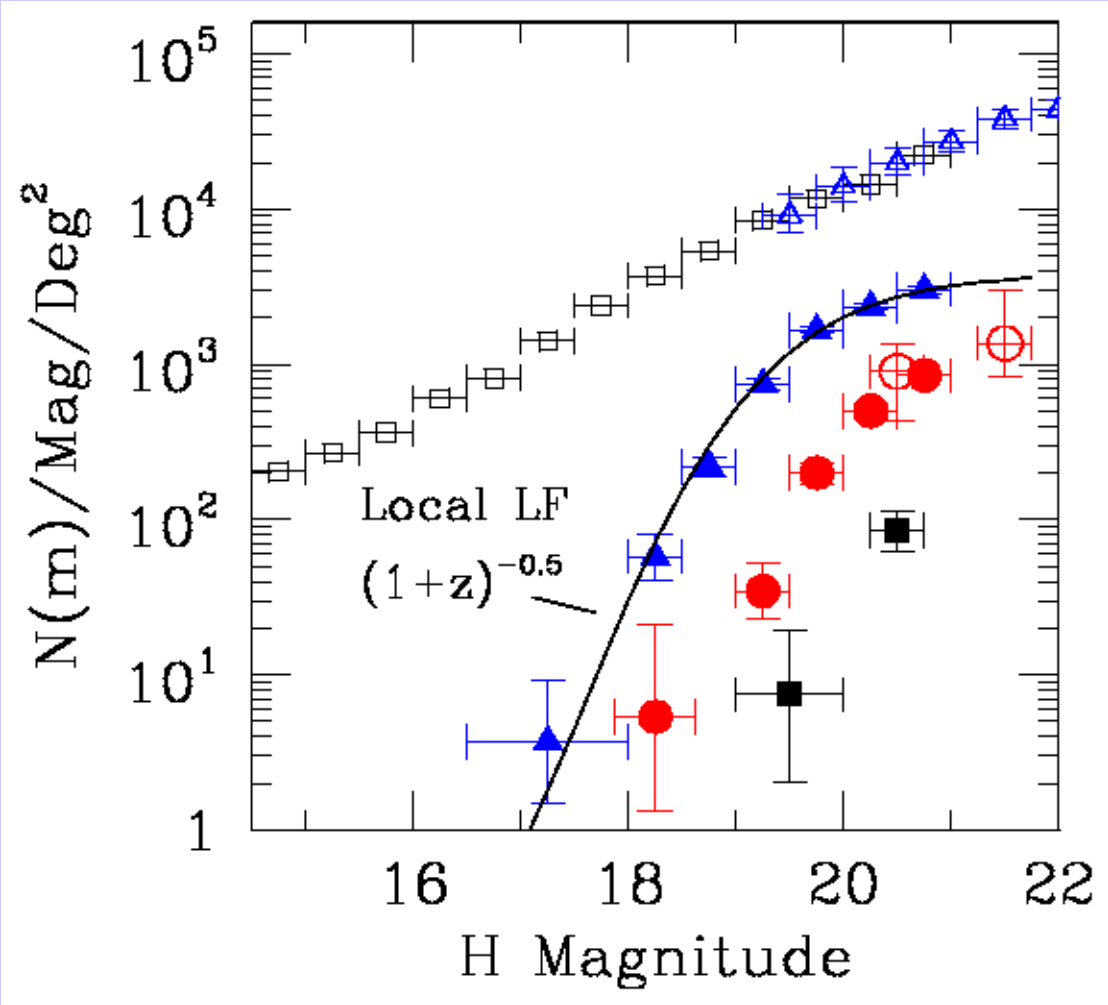
I-K > 4.0

I-K > 4.5

I-K > 5.0

I-K > 5.5

# Number-Magnitude Relations



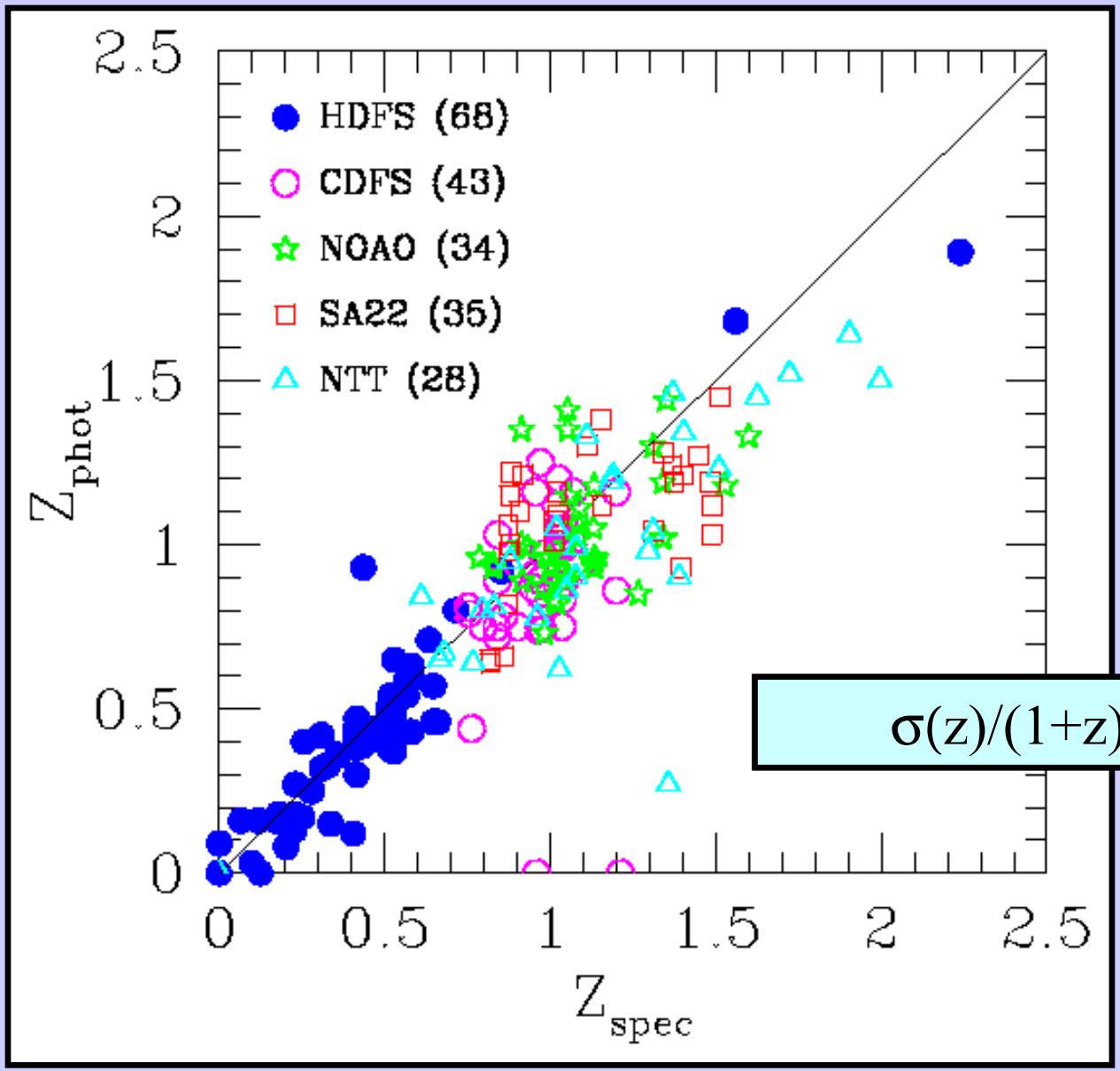

I-K > 4.0

I-K > 4.5

I-K > 5.0

Gardner et al
K-band LF

# Photometric Redshifts from LCIR

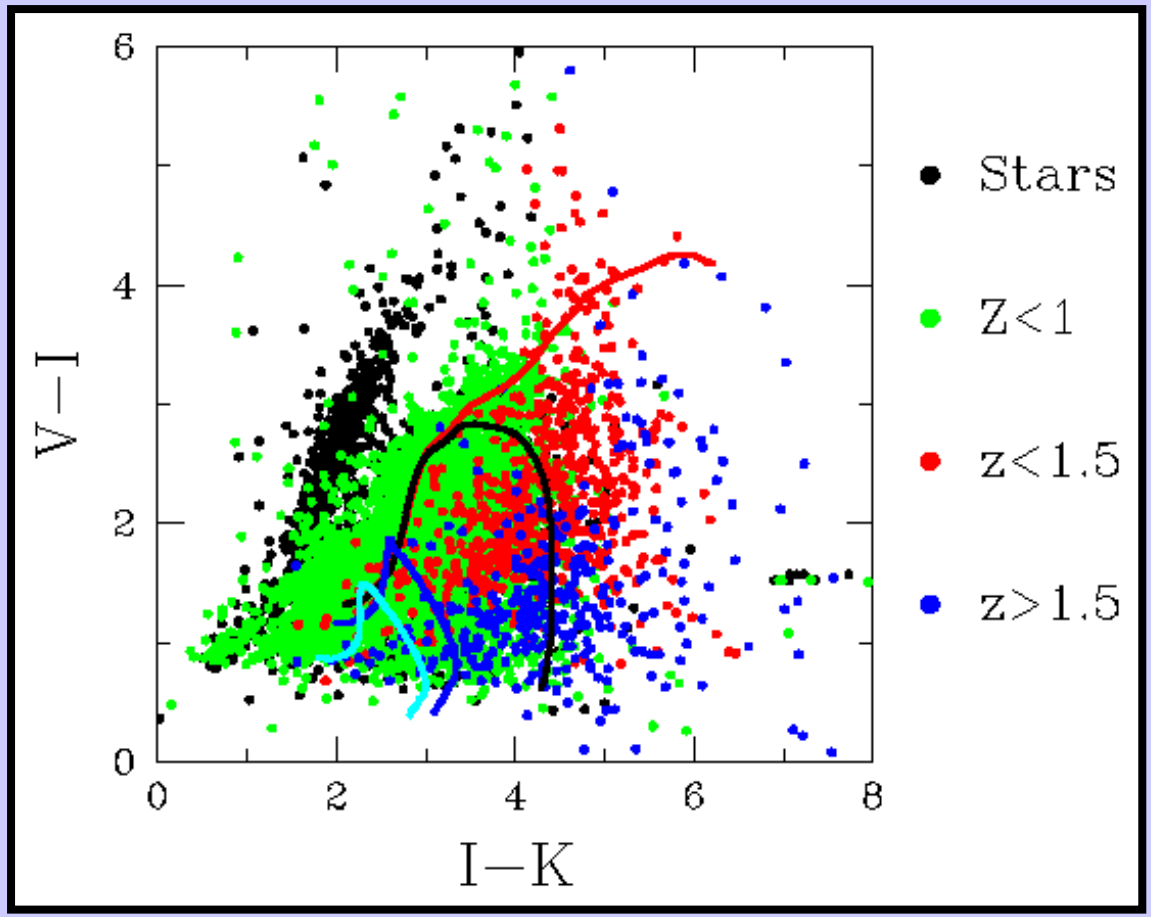



H.-W. Chen et al in prep

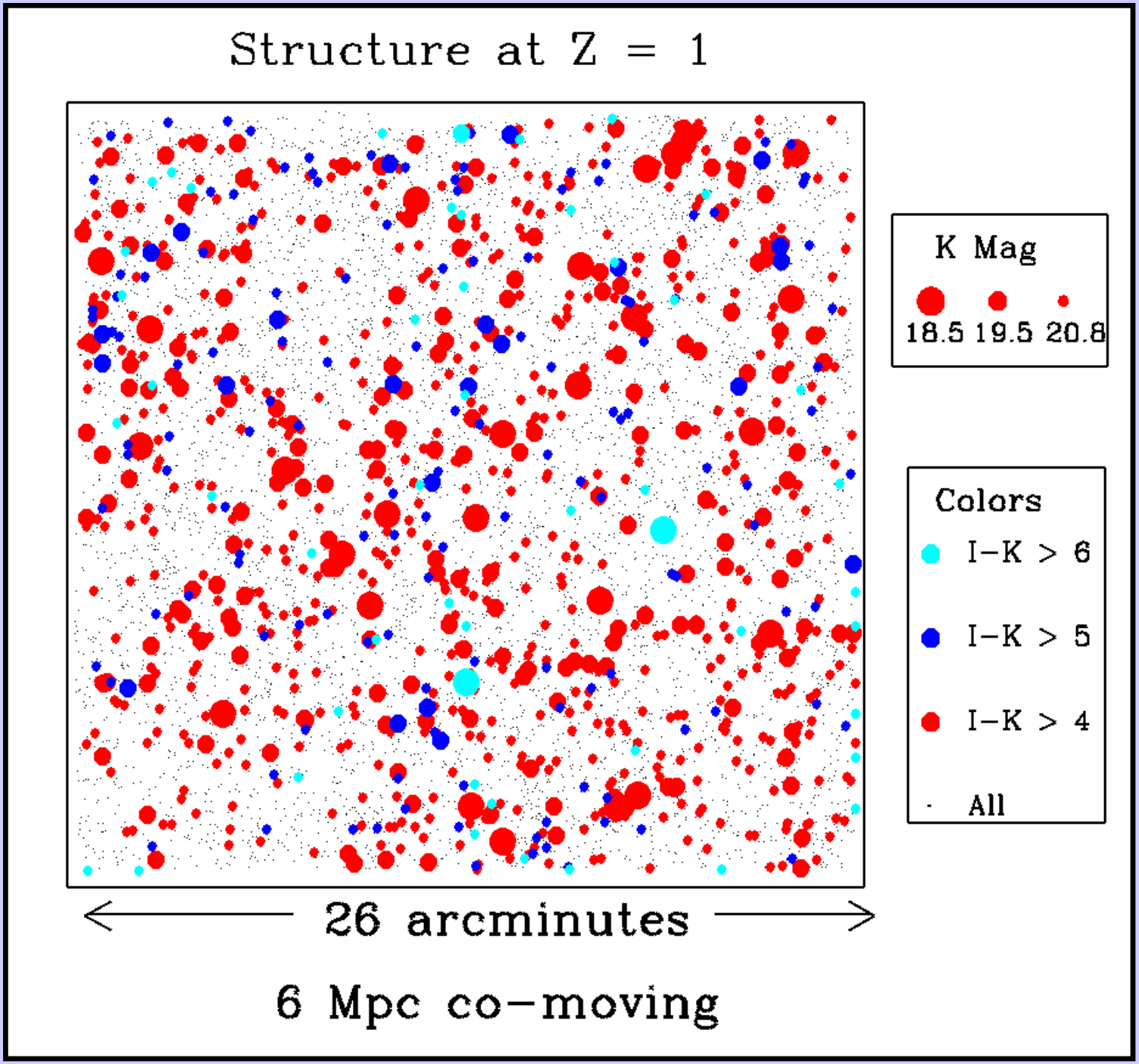
$\sigma(z)/(1+z) = 0.08$

# Color-Color Diagrams

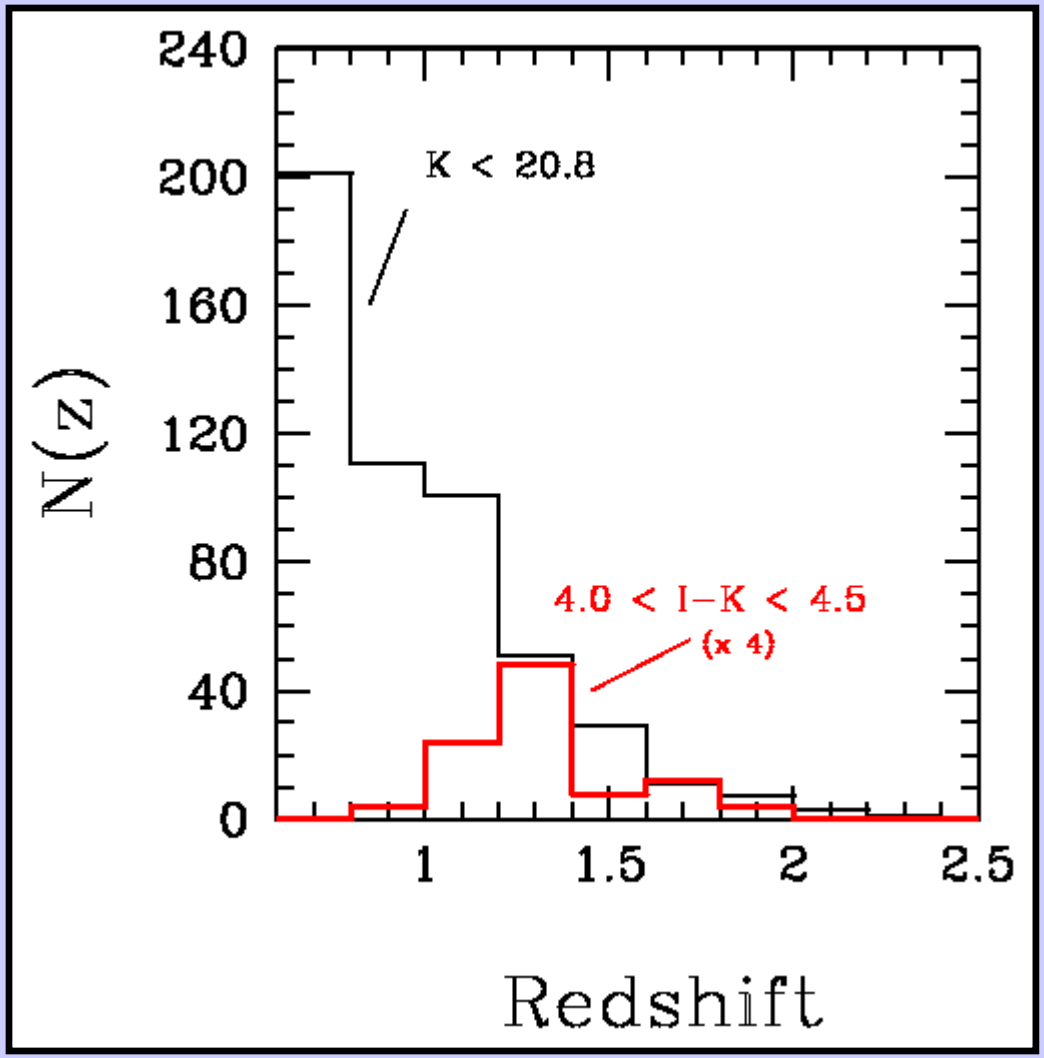
- Stars form distinct sequence
- Z > 1 galaxies appear at K ~ 19
- Z > 1.5 galaxies at K ~ 20
- Reddest galaxies follow minimal evolution track




K < 20.8


Structure at Z = 1
K Mag
18.5 19.5 20.8
Colors
I−K > 6
I−K > 5
I−K > 4
All
26 arcminutes
6 Mpc co−moving

# N(z) for I-K selected subsamples




LDSS2 + Magellan

Bridge, Bunker, PMc

LRIS + Keck

Ellis, Bunker, PMc

GMOS+Gemini N

Abraham et al.

# Clustering Scale Length

- Angular clustering length ~ 12”
- $\langle z \rangle = 1.2 \quad \sigma(z) \sim 0.15$
- $r_0 \sim 9\ h^{-1}$ Mpc co-moving

*Comparable to or larger than the most strongly clustered populations today*

*Note - LBG scale length ~ 2-3$h^{-1}$ Mpc*

Daddi et al. (2001,2003); McCarthy et al. (2002)

Giavalisco

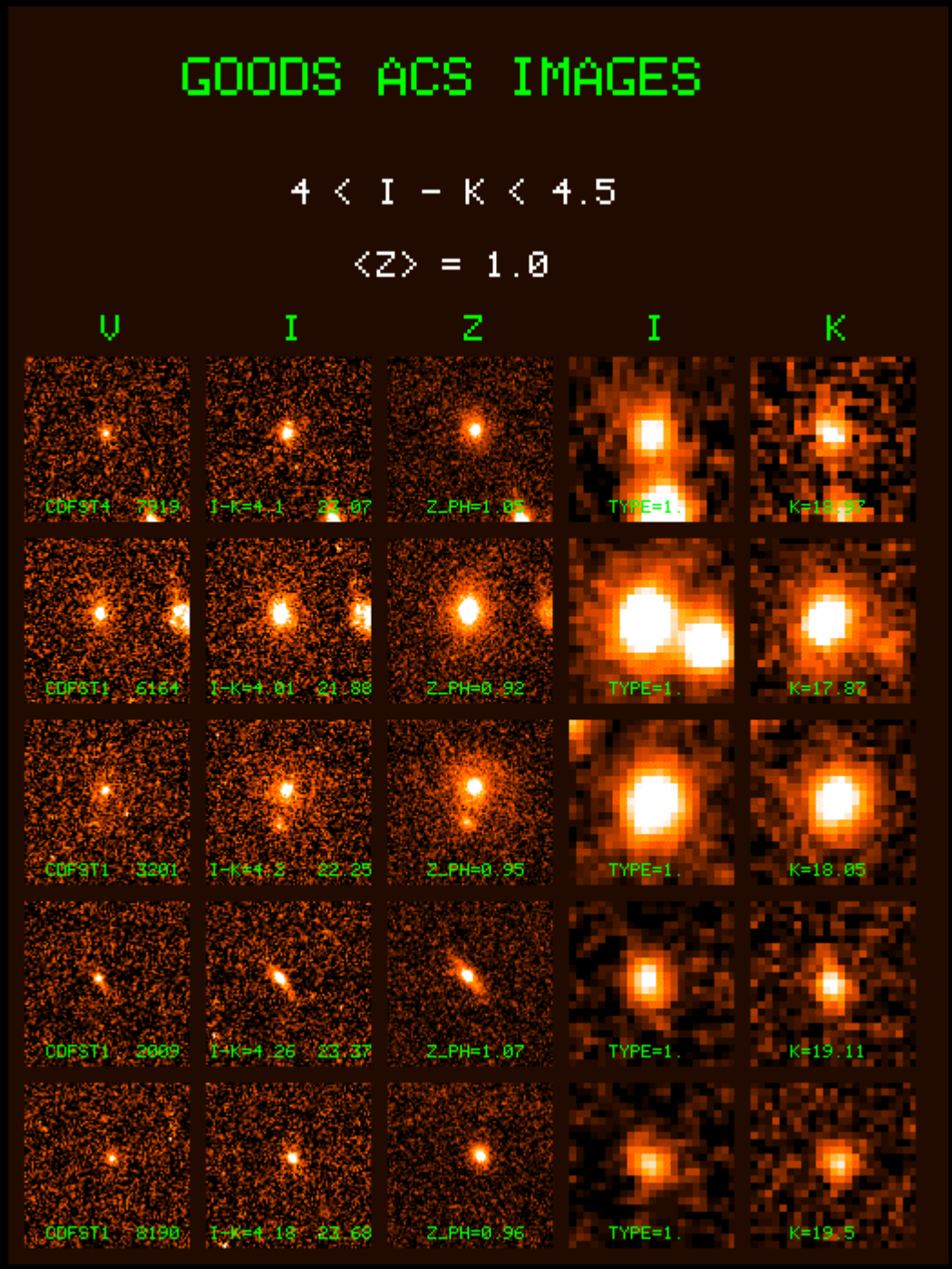
et al

Cycle 11

Treasury

Program

10/5/02
public release




E/S0

Template

Match

91 objects

Giavalisco

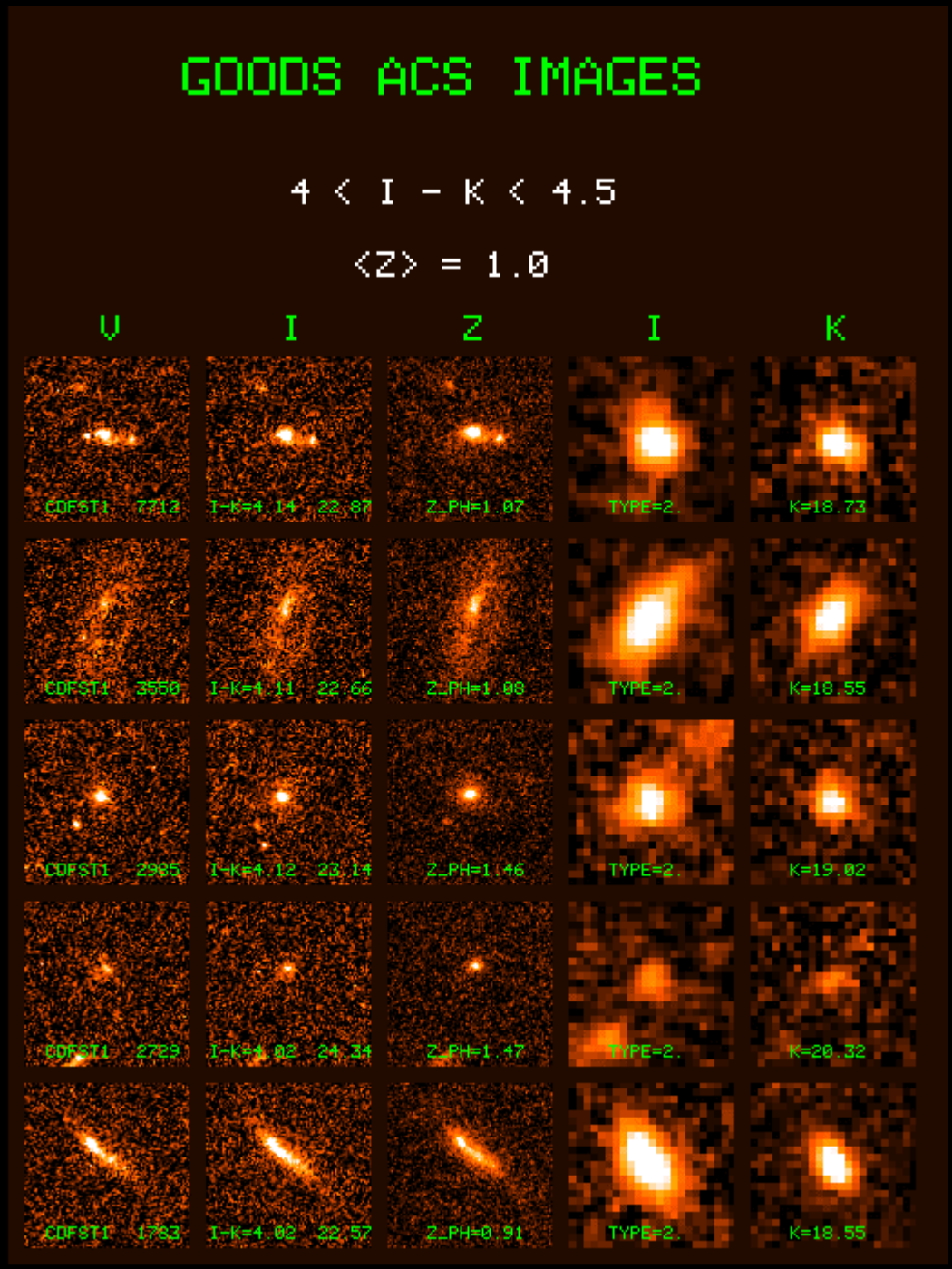
et al

Cycle 11

Treasury

Program

10/5/02
public release




Sab/Sbc

Template

Match

# Morphologies of Red Galaxies

$4.0 < I - K < 4.5 \quad \langle z \rangle = 1.0$

Template type 1 (E/S0)

**85% Compact** 10% Disks 5% Diffuse

Template type 2 (Sab/Sbc)

**60% Compact** 35% Disks 5% Diffuse

See Stiavelli & Treu 1999 NICMOS results

$4.5 < I - K < 5.0 \quad \langle z \rangle = 1.2$

Template type 1 (E/S0)

60% Compact 25% Disks 15% Diffuse

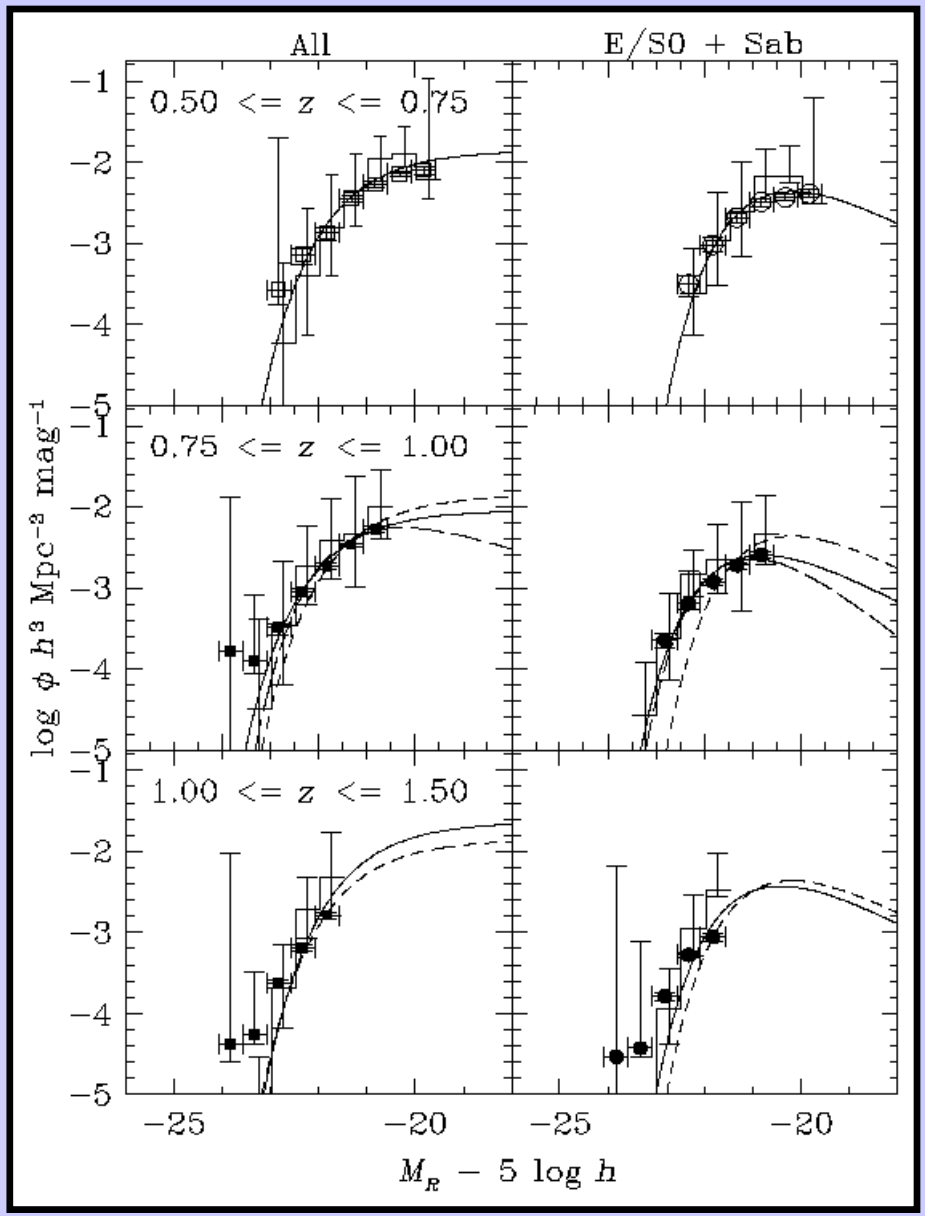
Template type 2 (Sab/Sbc)

40% Compact 30% Disks 30% Diffuse

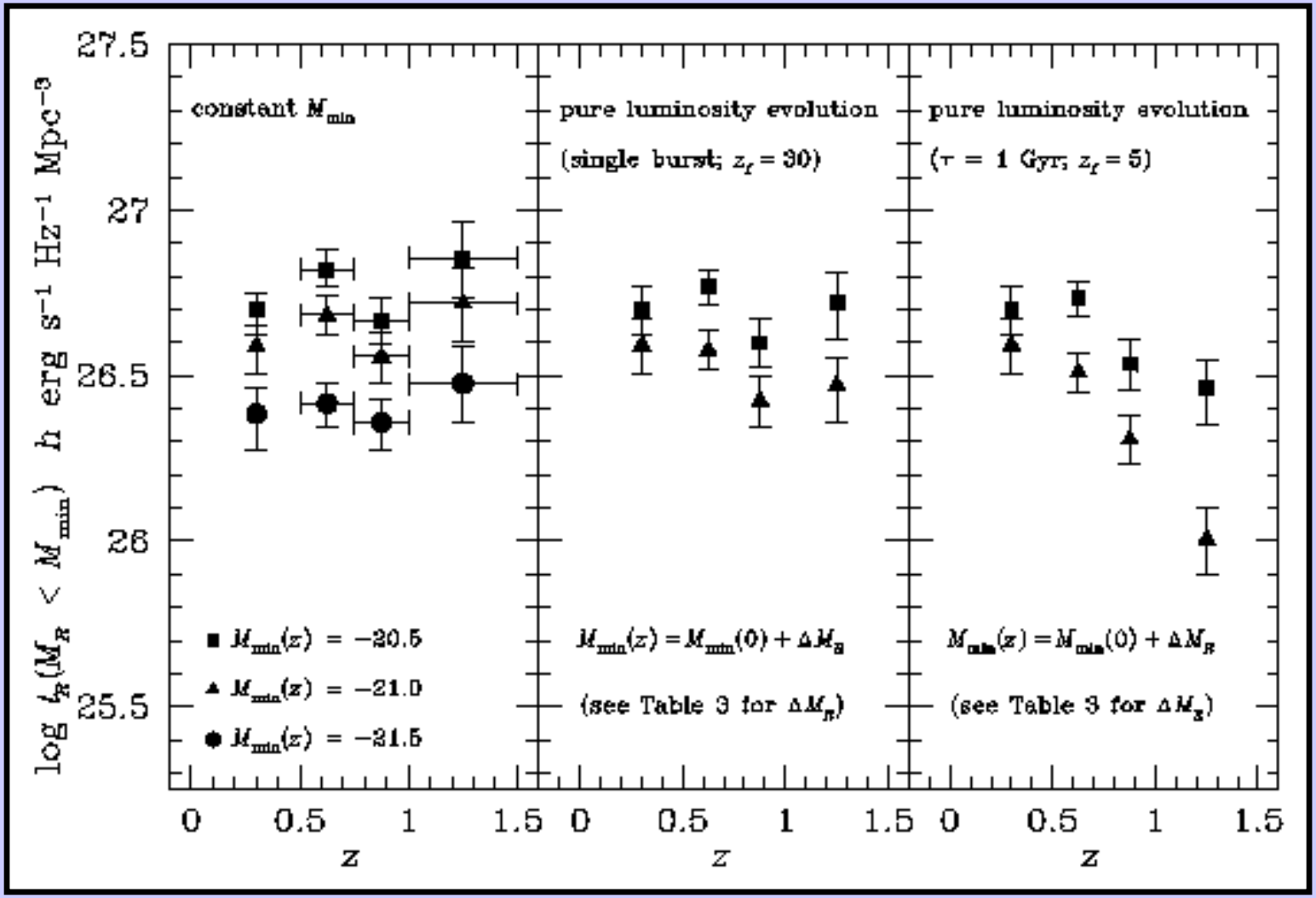
See Yan & Thompson 2002 WFPC2 results

# Evolving Luminosity Functions

- LFs derived from photo-z's with modified likelihood approach
- LF at intermediate z agrees well with CNOC2
- Very little apparent evolution in L* to z ~ 1.2



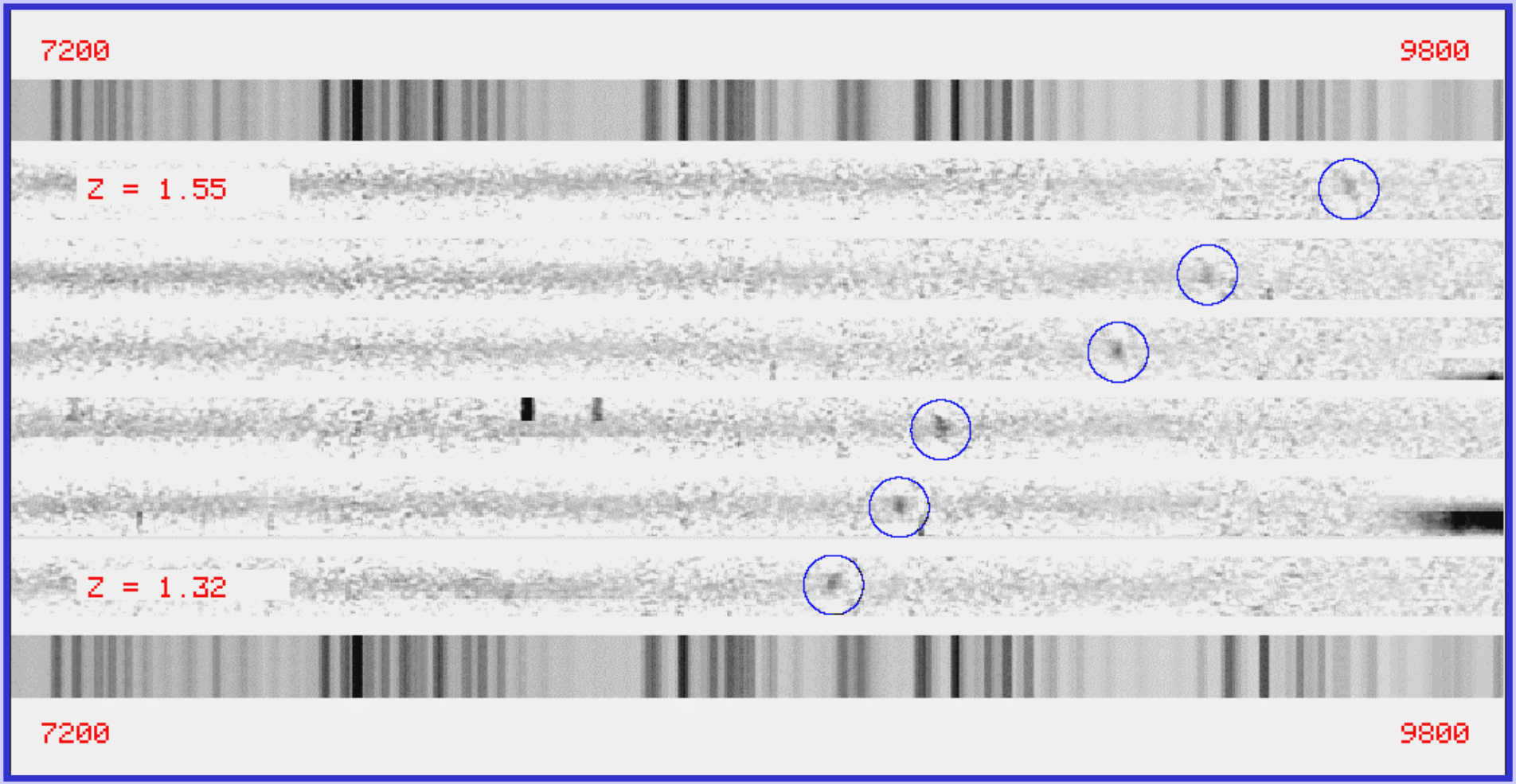
# Rest-Frame R-and Luminosity Density




Chen et al. 2003

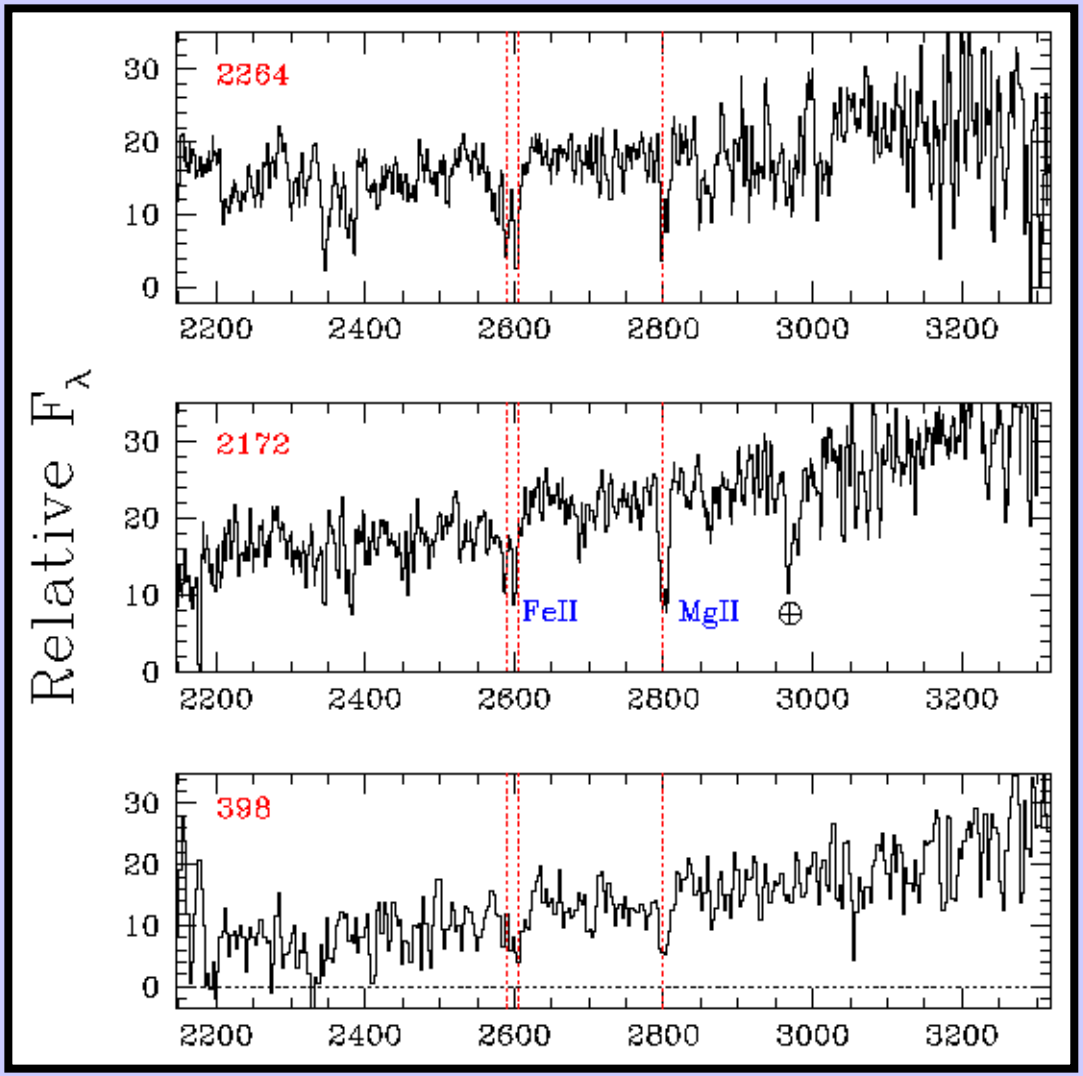
Little or no evolution to z ~ 1.3

# [OII] Redshifts from GDDS




23.7 < I(Vega) < 24.2

# Absorption Line Spectra




I = 24.0

Z = 1.67

I = 23.7

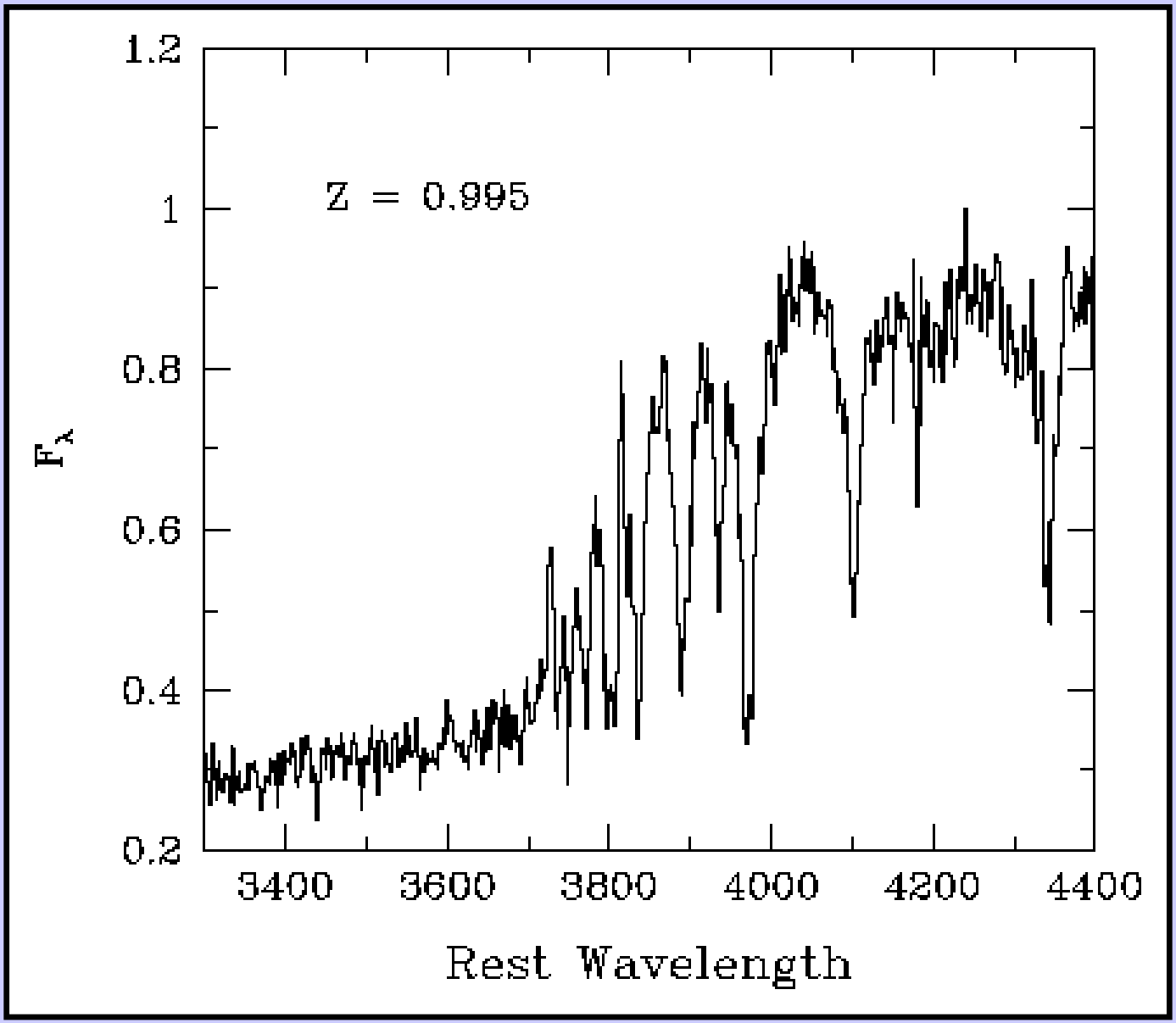
Z = 1.56

I = 24.2

Z = 1.39

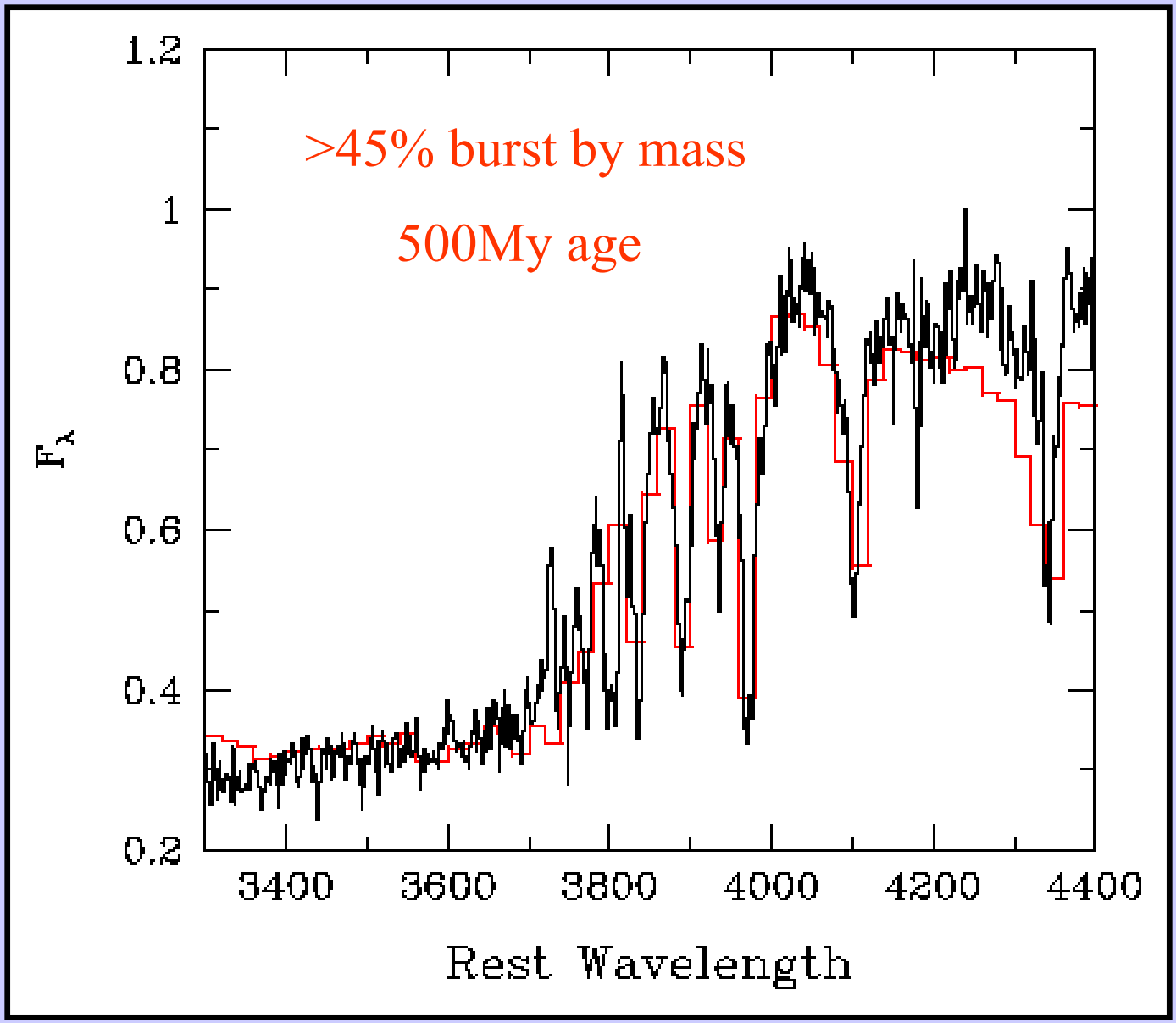
# K + A Galaxies

Only 1 in 10,000 galaxies in LCRS have similar EWs

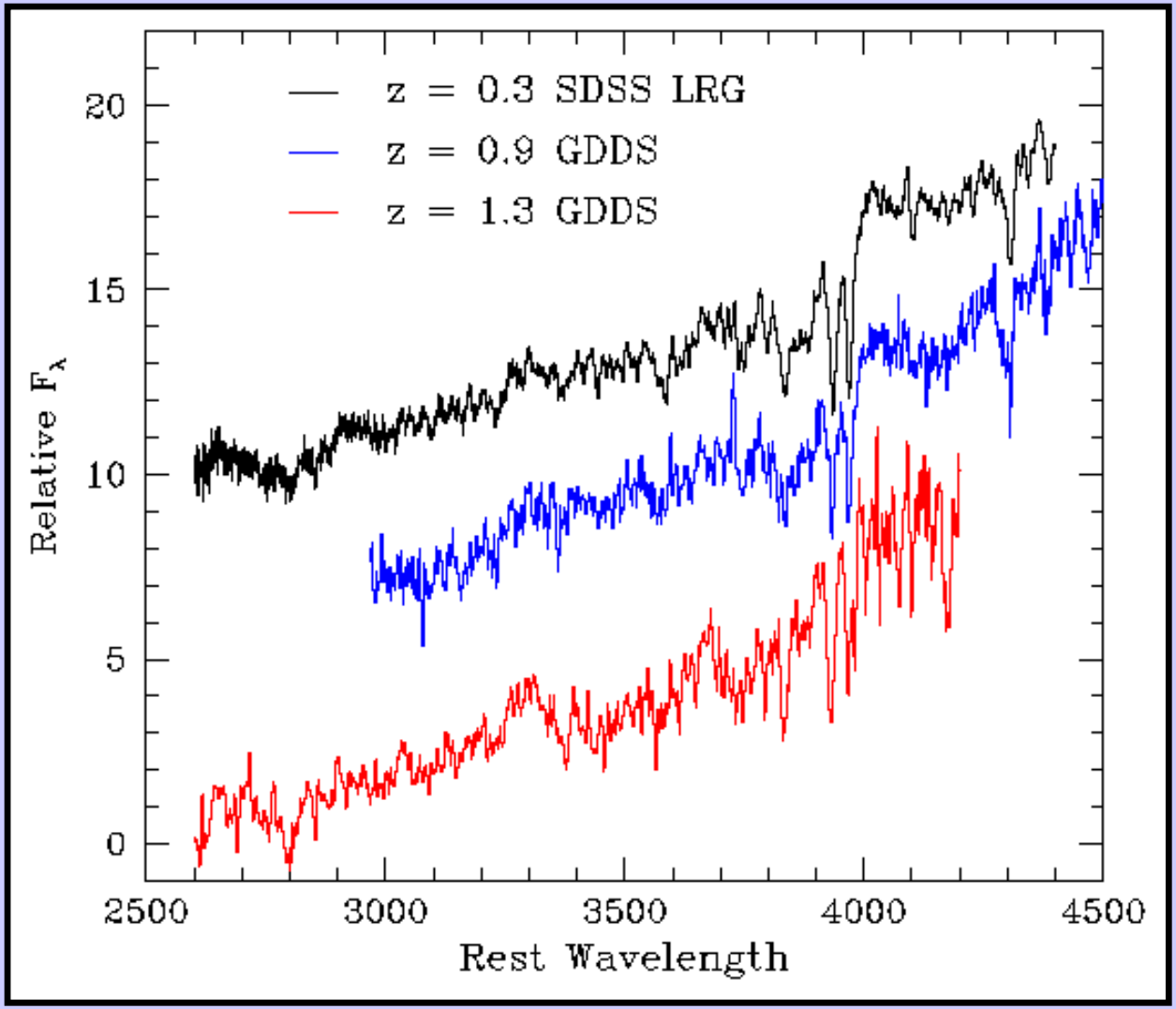


# K + A Galaxies

~5% of red galaxies are in this class!



# The Reddest Galaxies



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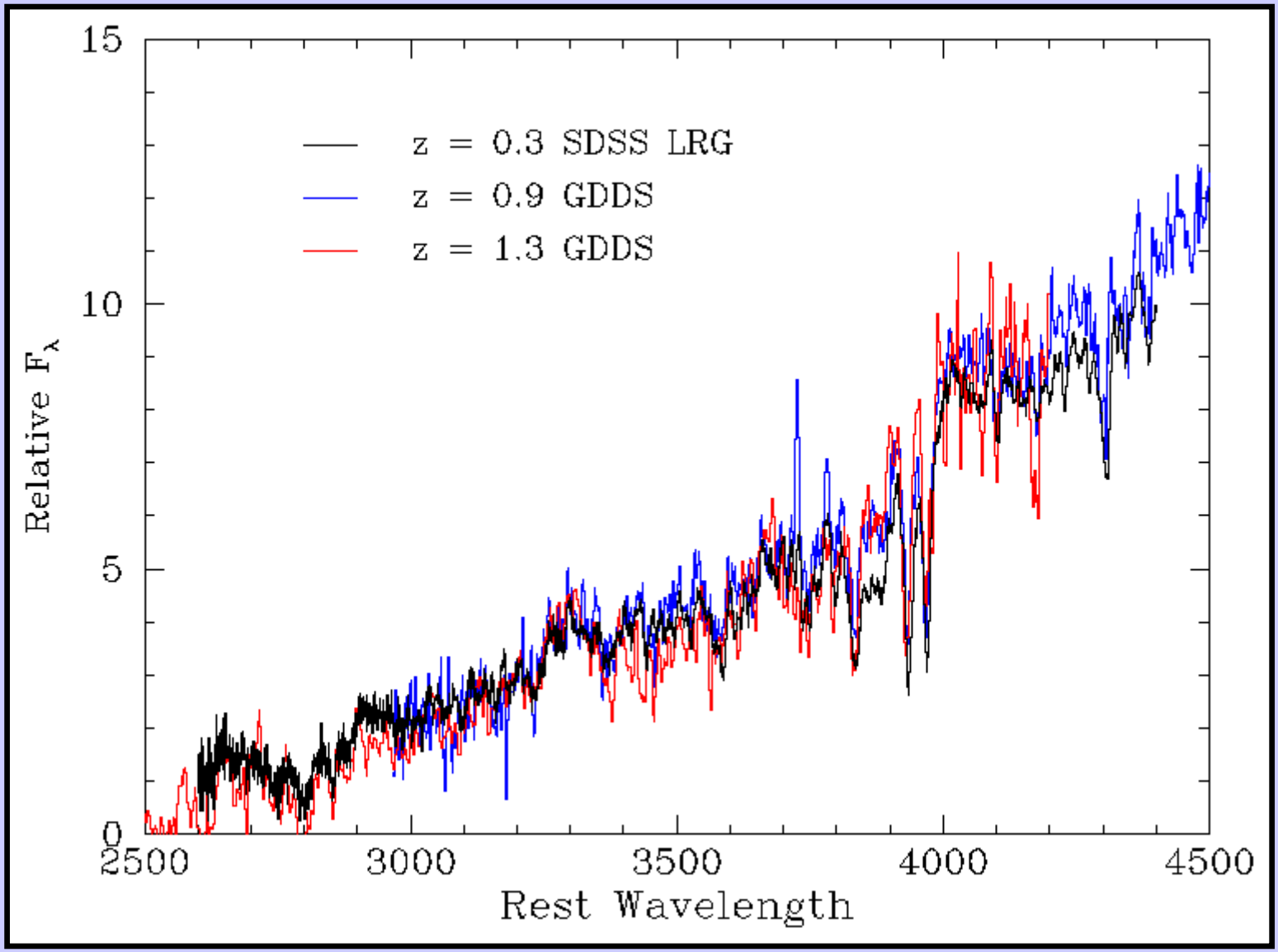

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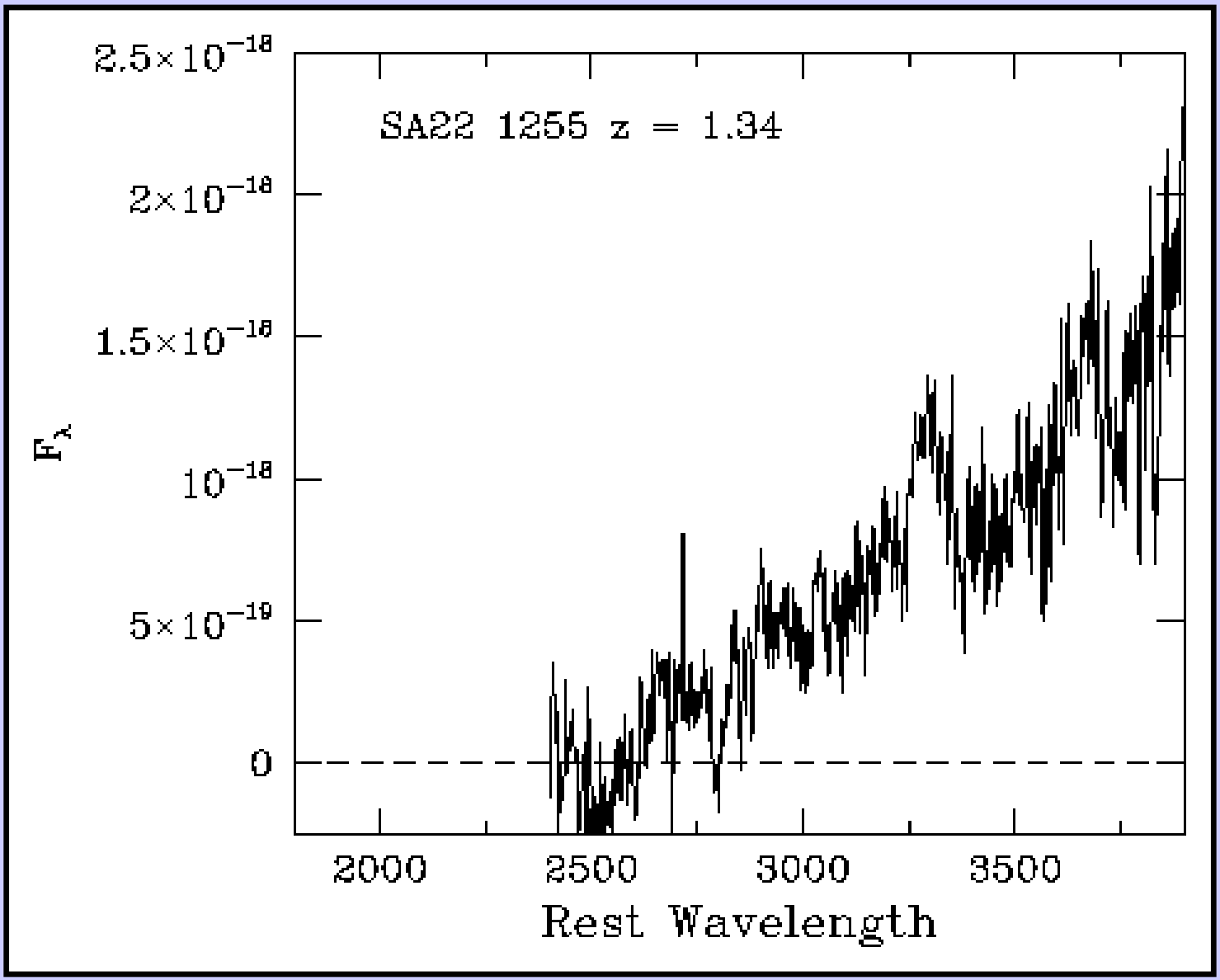

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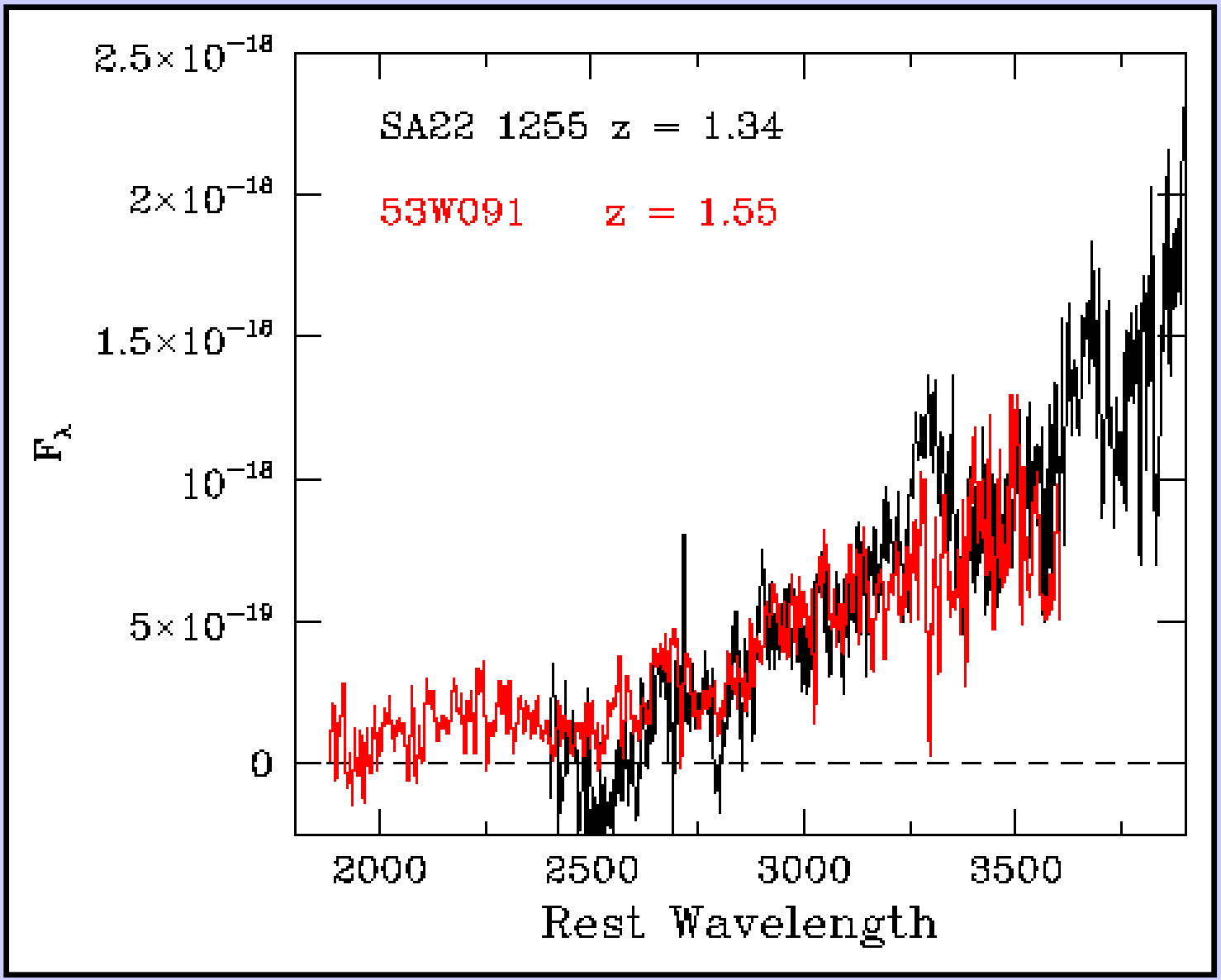

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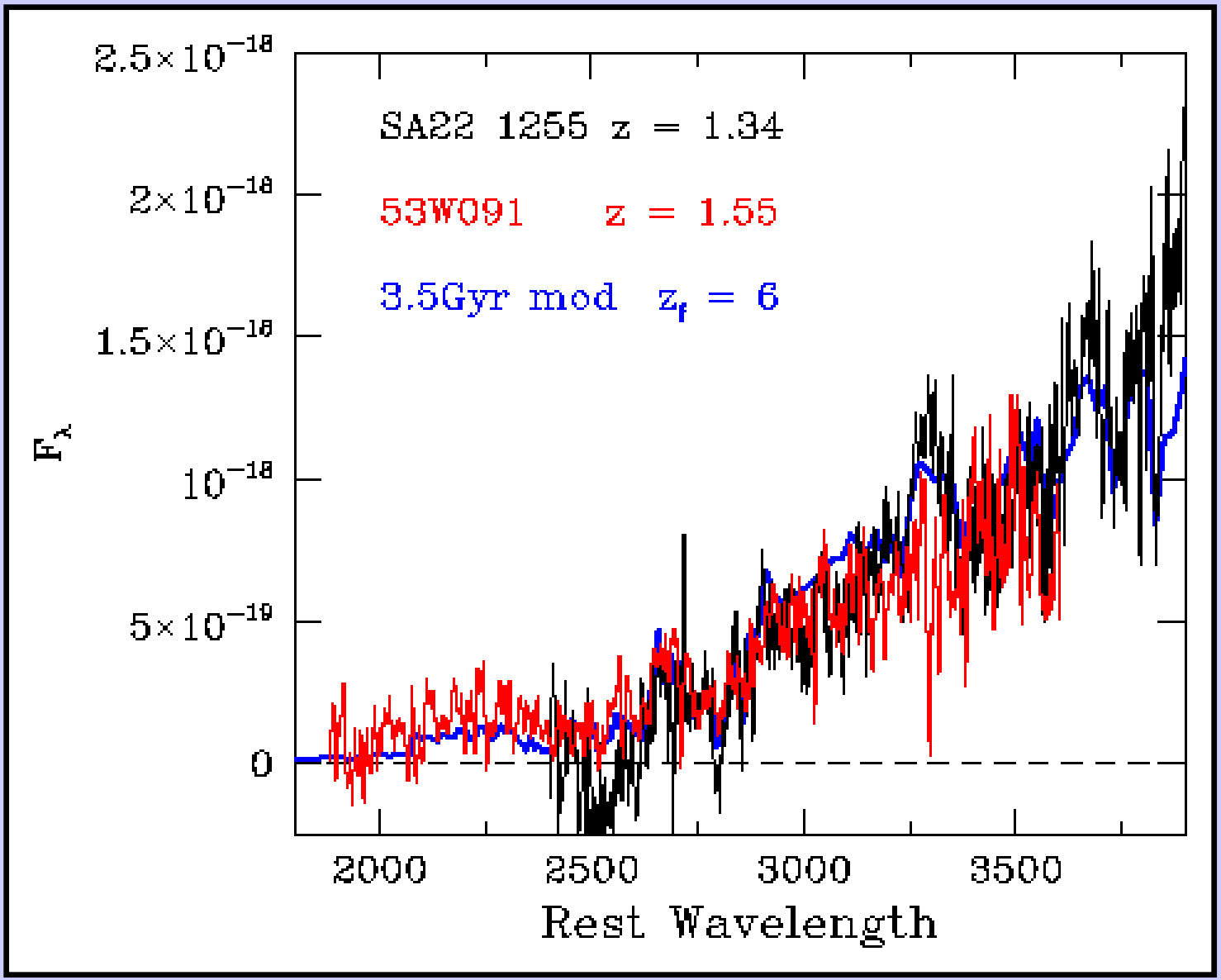
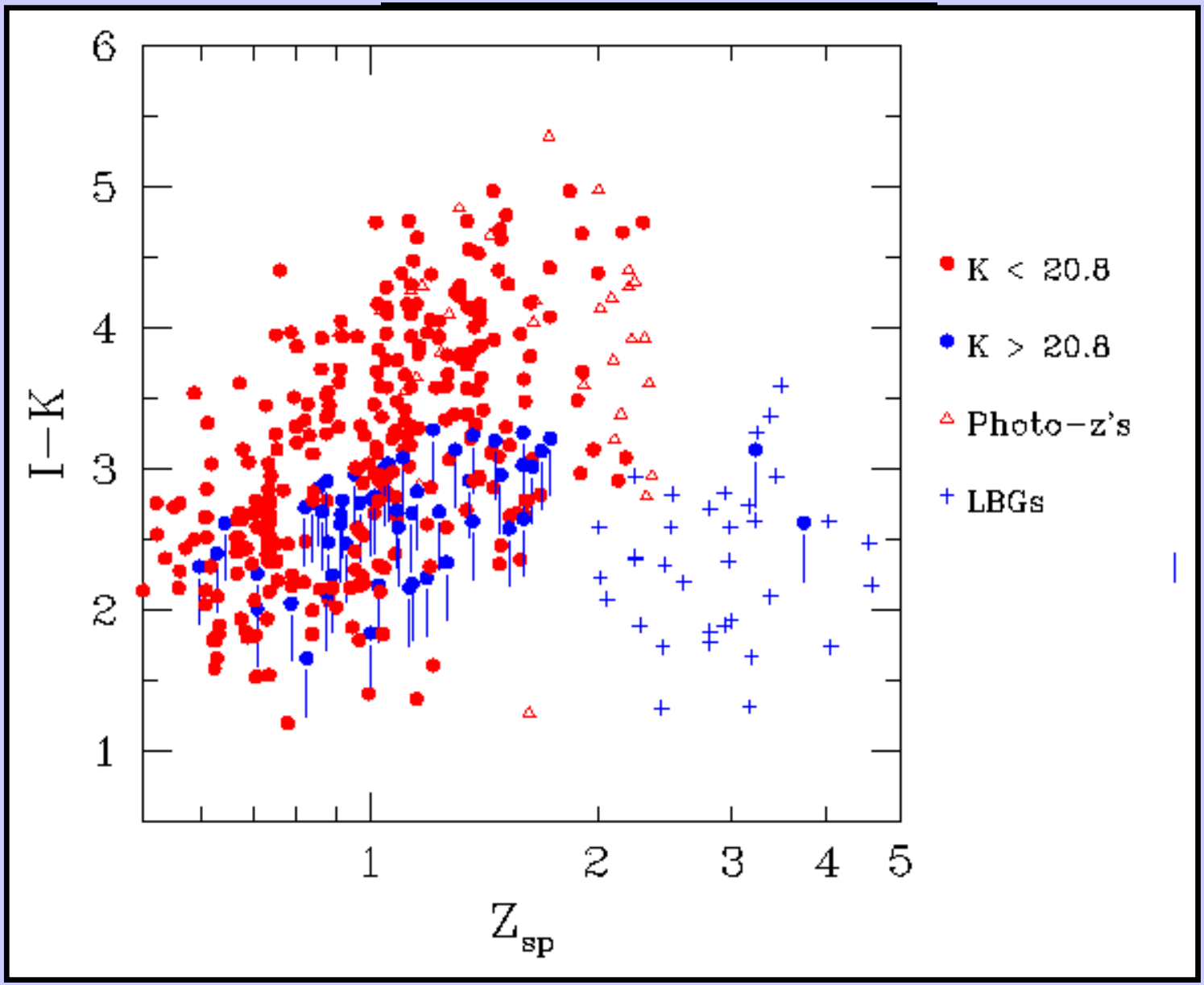


# Color Evolution



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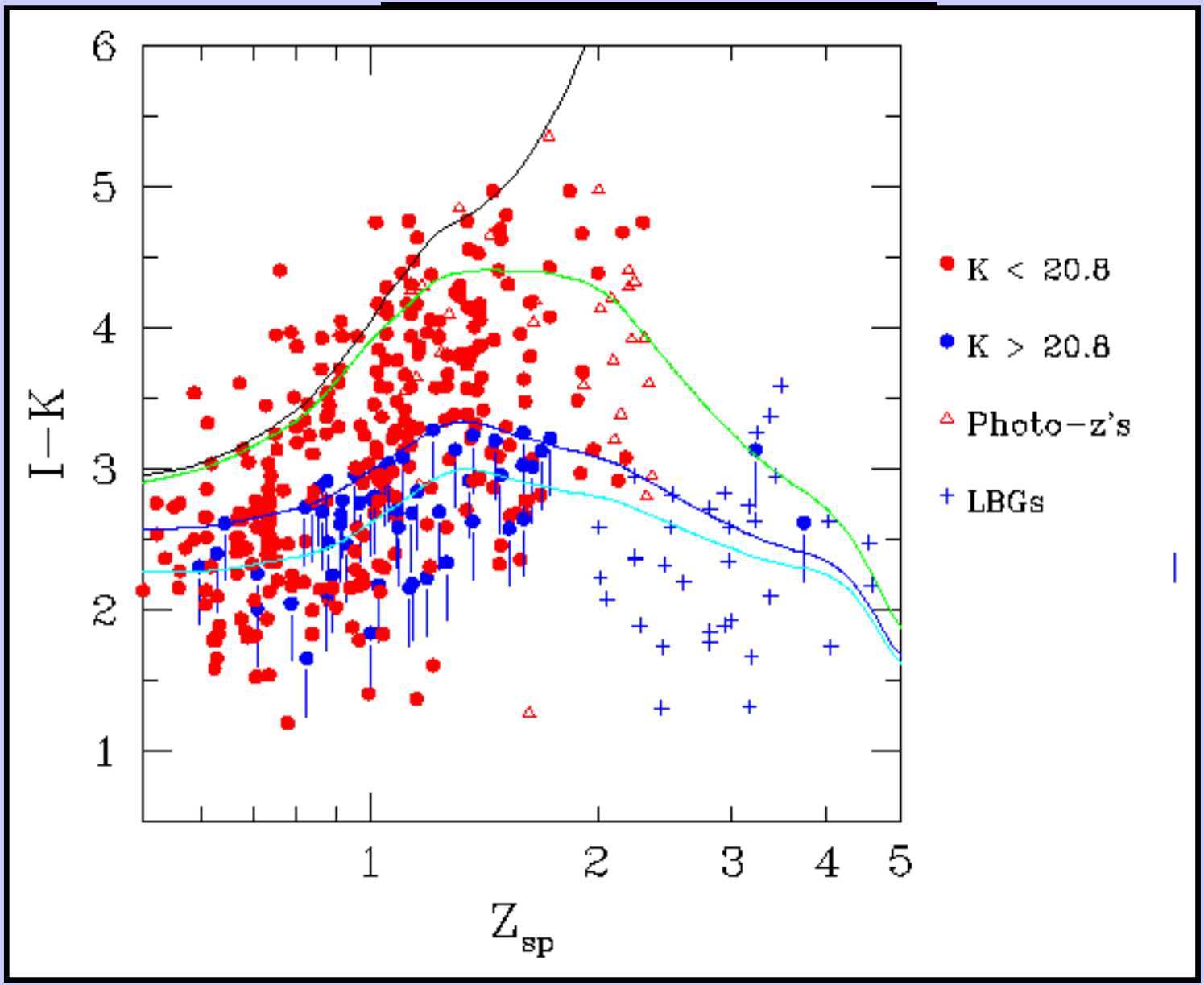

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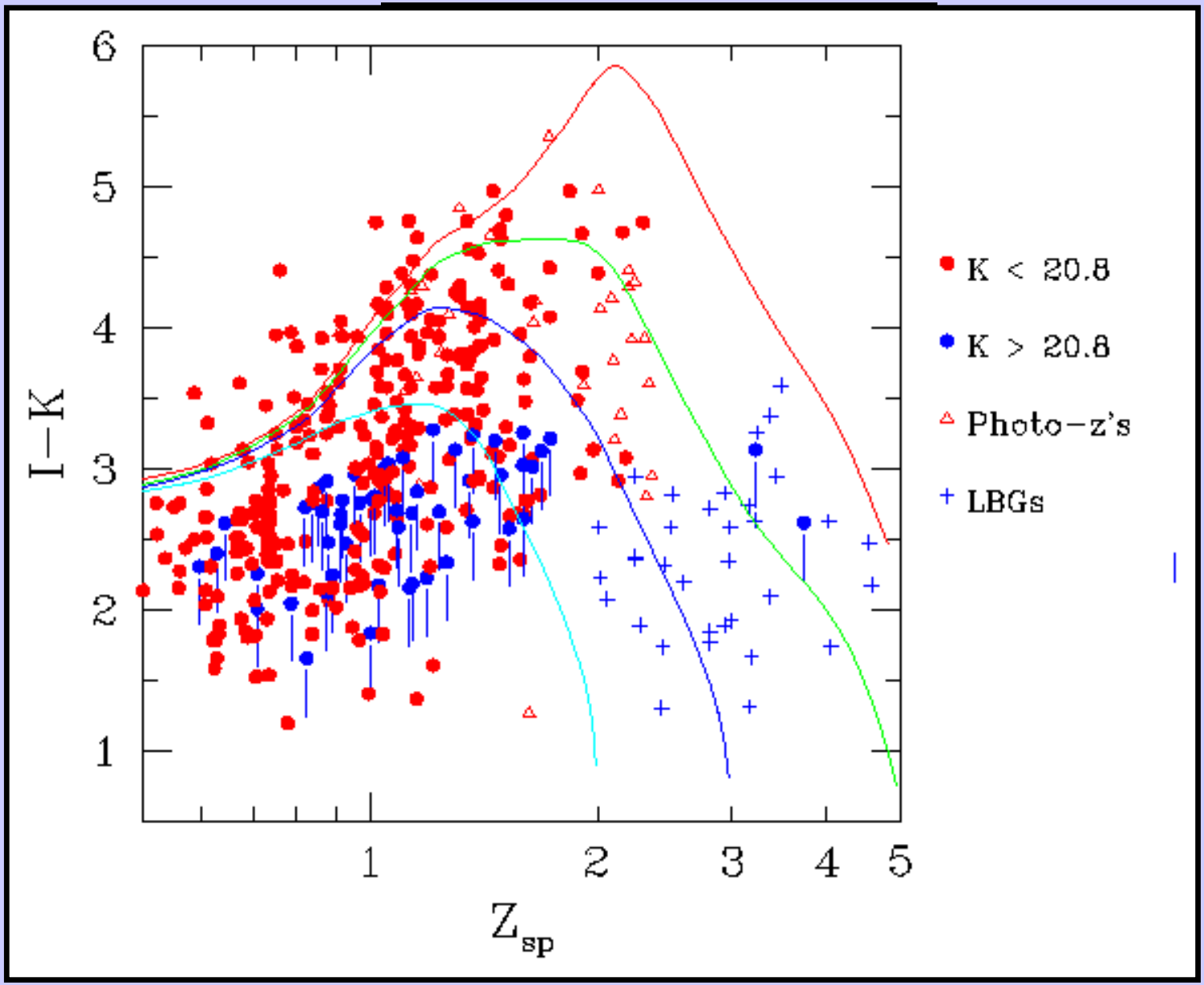

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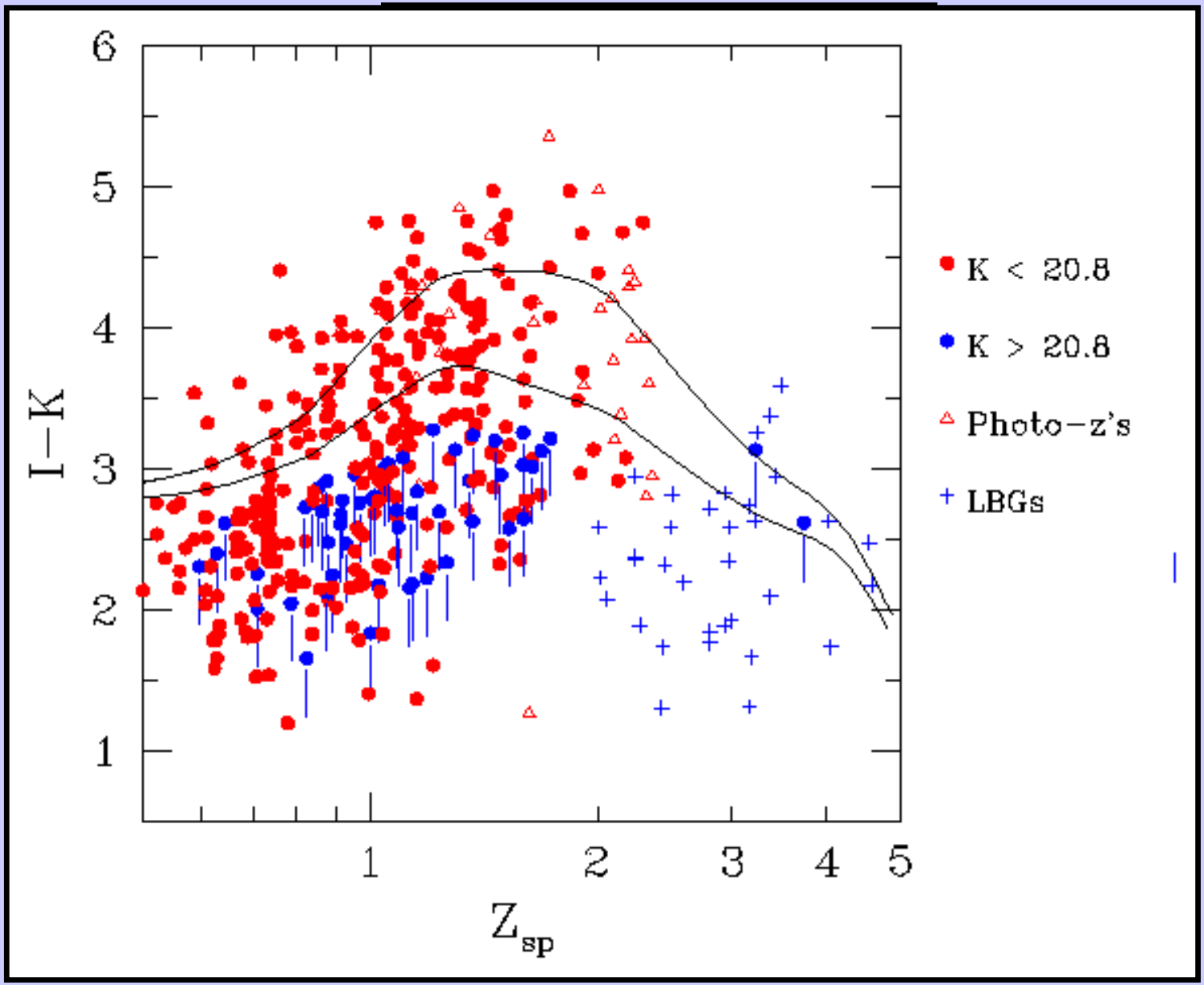

# Are the Red galaxies the descendants of the LBGs?

- Clustering ✗
- Color evolution ✗ ?
- Spectral Shapes ✓
- Masses ?

If not, what are the progenitors?

sub-mm sources? red J-K galaxies?

# Conclusions

- I-K > 4 → z > 1
- Progenitors to Local E's have been found
- Little or no Evolution in Mass Density Since Z ~ 1.5
- Old Stellar Populations at z ~ 2

  → ***Large Formation Redshifts***