

Searches for $z > 1$ Clusters in the IRAC Shallow Survey

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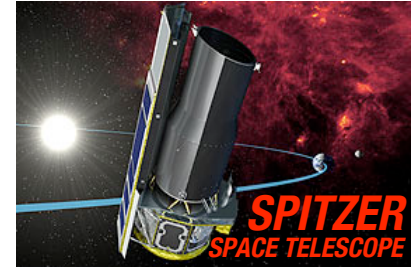
G.Fazio, G. Rieke, M. Rieke, M. Werner, E. Wright,

M. Brown, A. Dey, B. Jannuzi, G. Tiede, A. Gonzalez

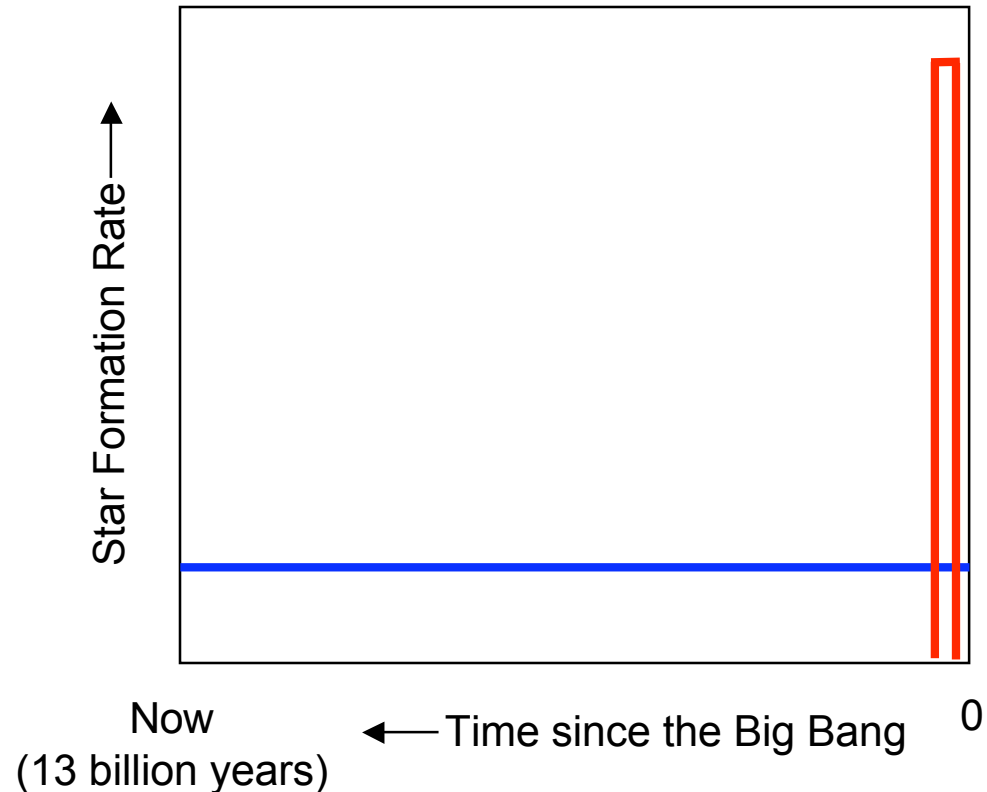
L. Allen, R. Arendt, M. Ashby, P. Barmby, W. Forrest, J. Hora, J.-S. Huang, J. Huchra, M. Pahre, J. Pipher, W. Reach, H. Smith, J. Stauffer, Z. Wang, S. Willner



History of Star Formation in Galaxies

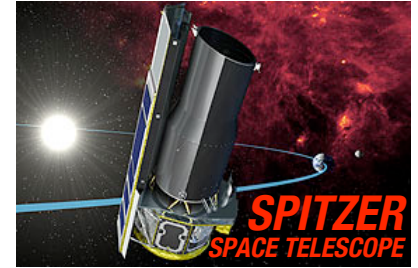


- Is the star formation history in cluster galaxies more like:
 - a delta function at high redshift, ending early in the history of the universe (red spike), or
 - a continuous process over cosmic time, still going on today (blue plateau) ?

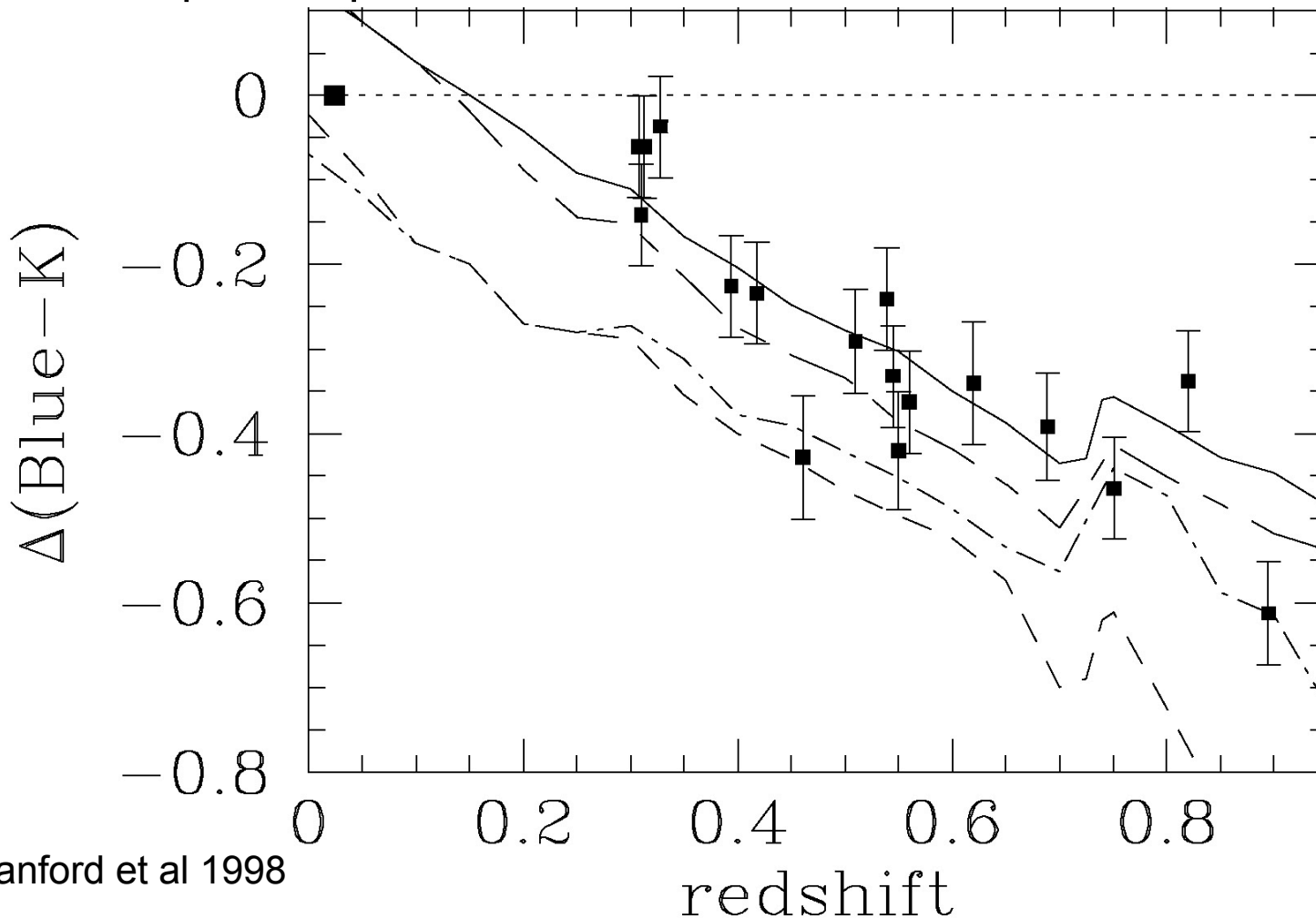




Color-Magnitude Intercept vs Redshift



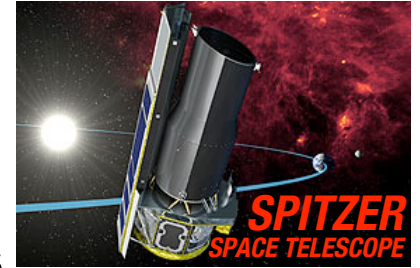
- The scatter, slope and intercept of the color-magnitude relation for cluster galaxies vs. redshift are better matched by a red spike, ie passive evolution with formation at $z > \sim 3$.



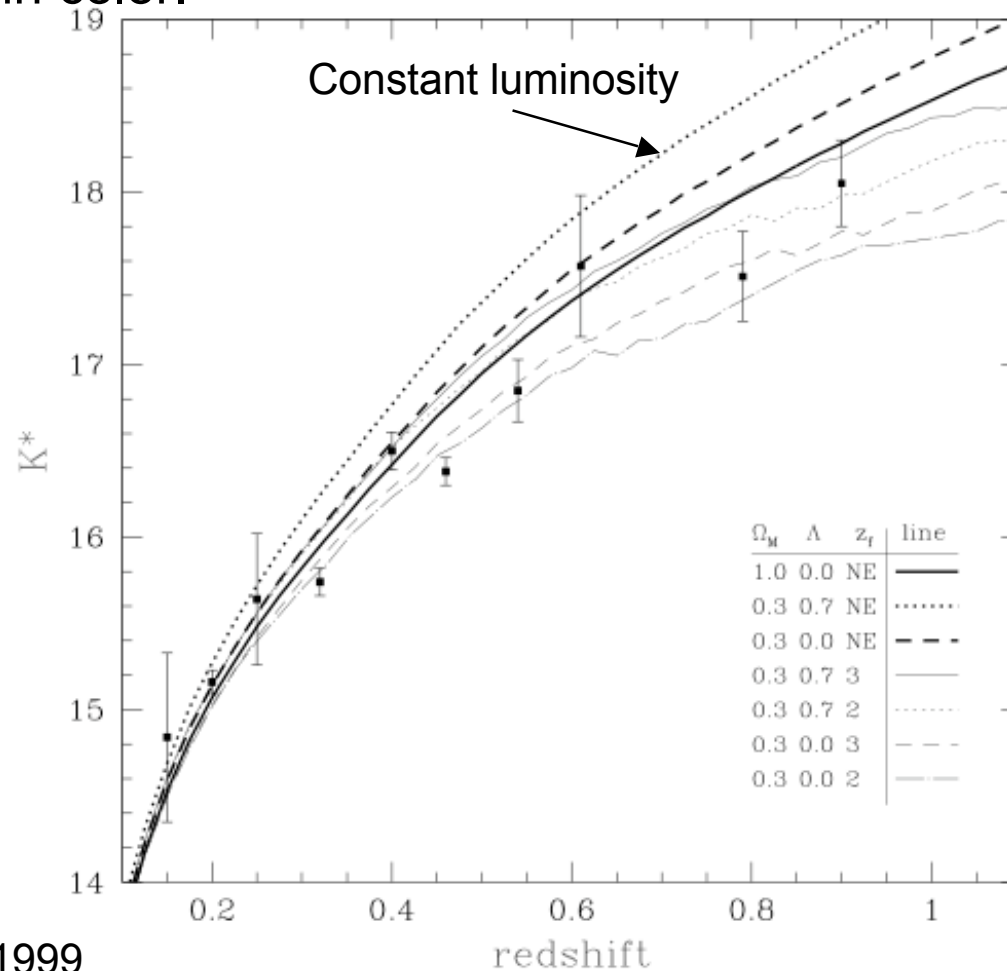
Stanford et al 1998



Infrared Luminosity vs Redshift



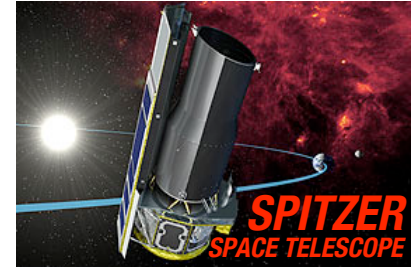
- The characteristic infrared luminosity of cluster galaxies (K^*) also increases with redshift, by an amount consistent with the changes in color.



De Propris et al 1999



$z > 1$ Clusters

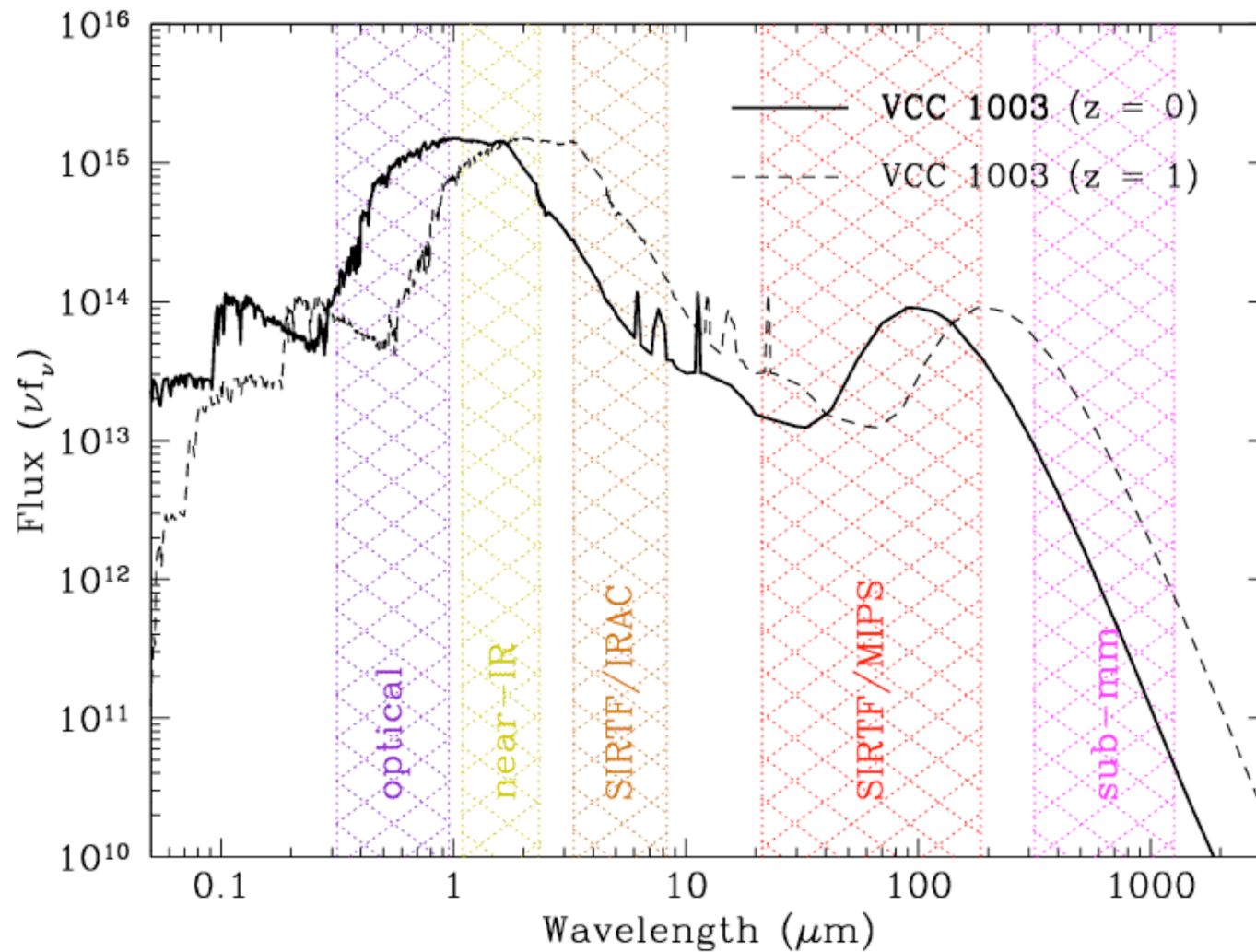
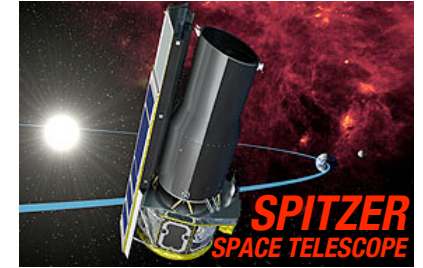


- Colors and magnitudes of cluster galaxies are consistent with simple passively evolving $z_f \sim 3$ model out to $z \sim 1$ (see e.g. Stanford 41.31)
- Need to test at $z > 1$
- But $z > 1$ clusters are hard to find optically because of foreground clutter

Stanford et al 1998

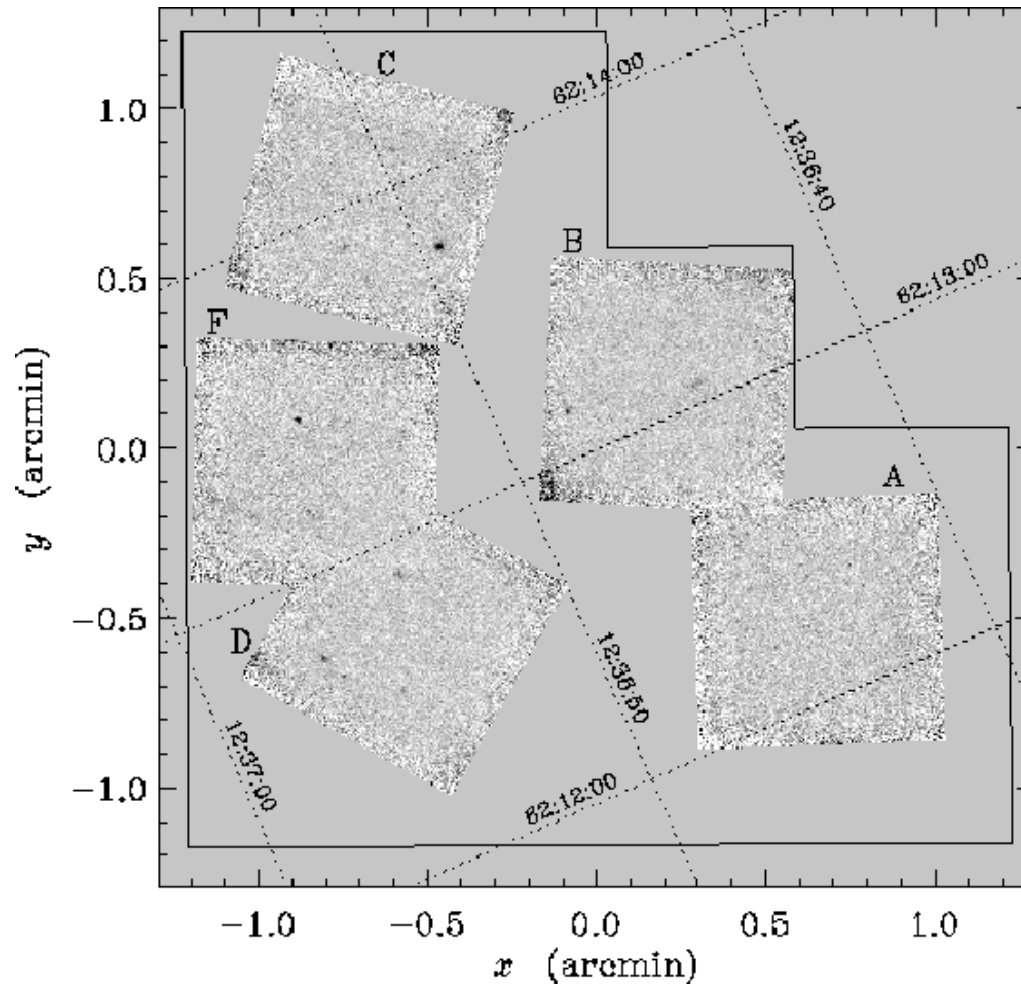
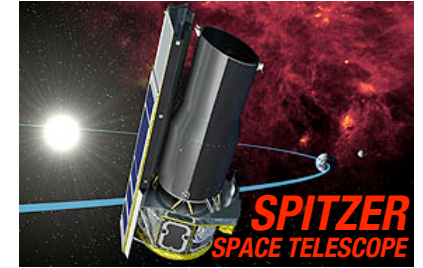


Mid-IR is a Good Place to Select Distant Galaxies





Ground-based Image of HDF-N at 3.2 microns

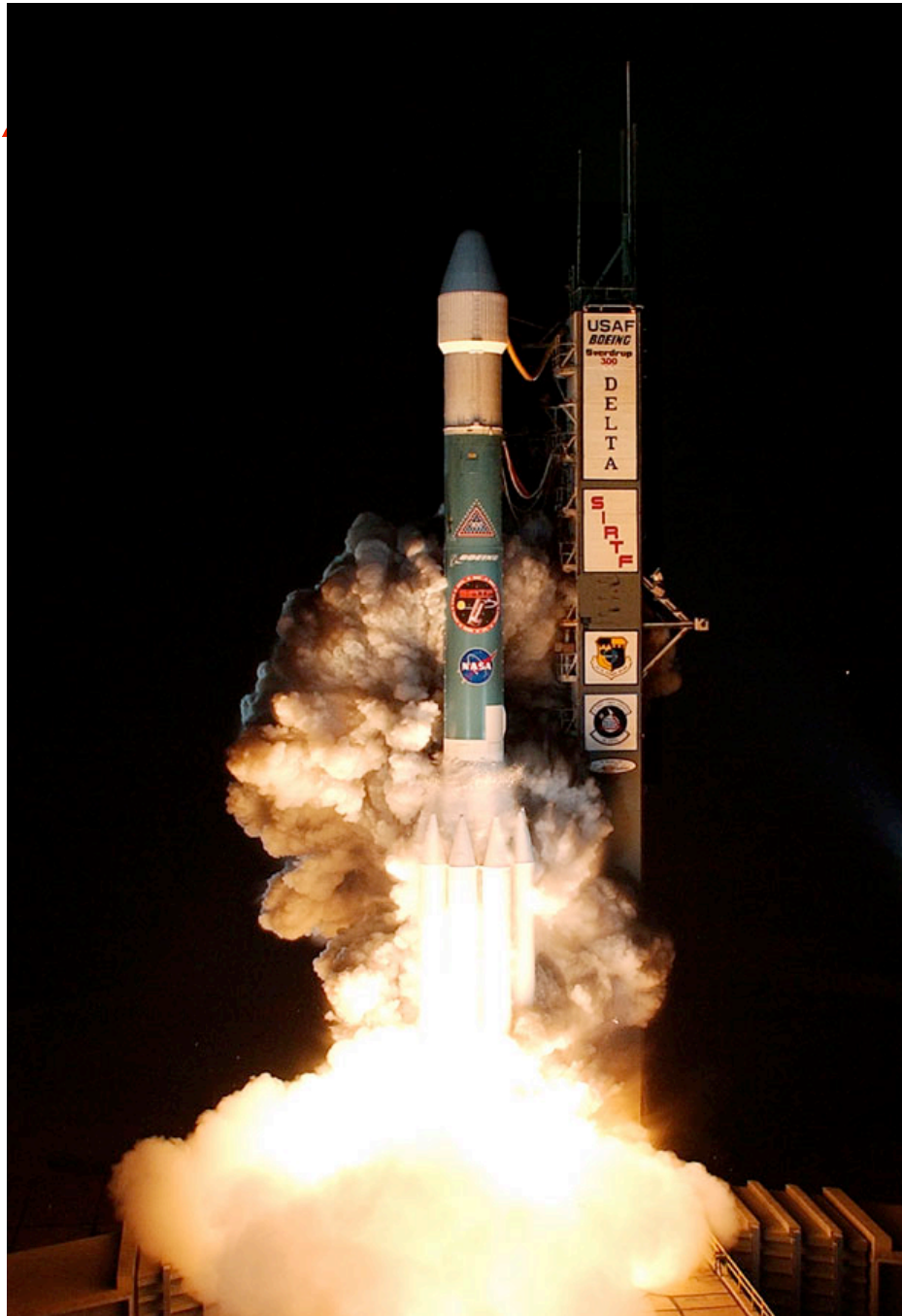


15 hours with Keck

2.5 square arcmin

11 sources detected

Hogg et al. (2000)



AAS-Denver

2004 June 2



Monday, August 25, 2003

1:35:39 AM EST

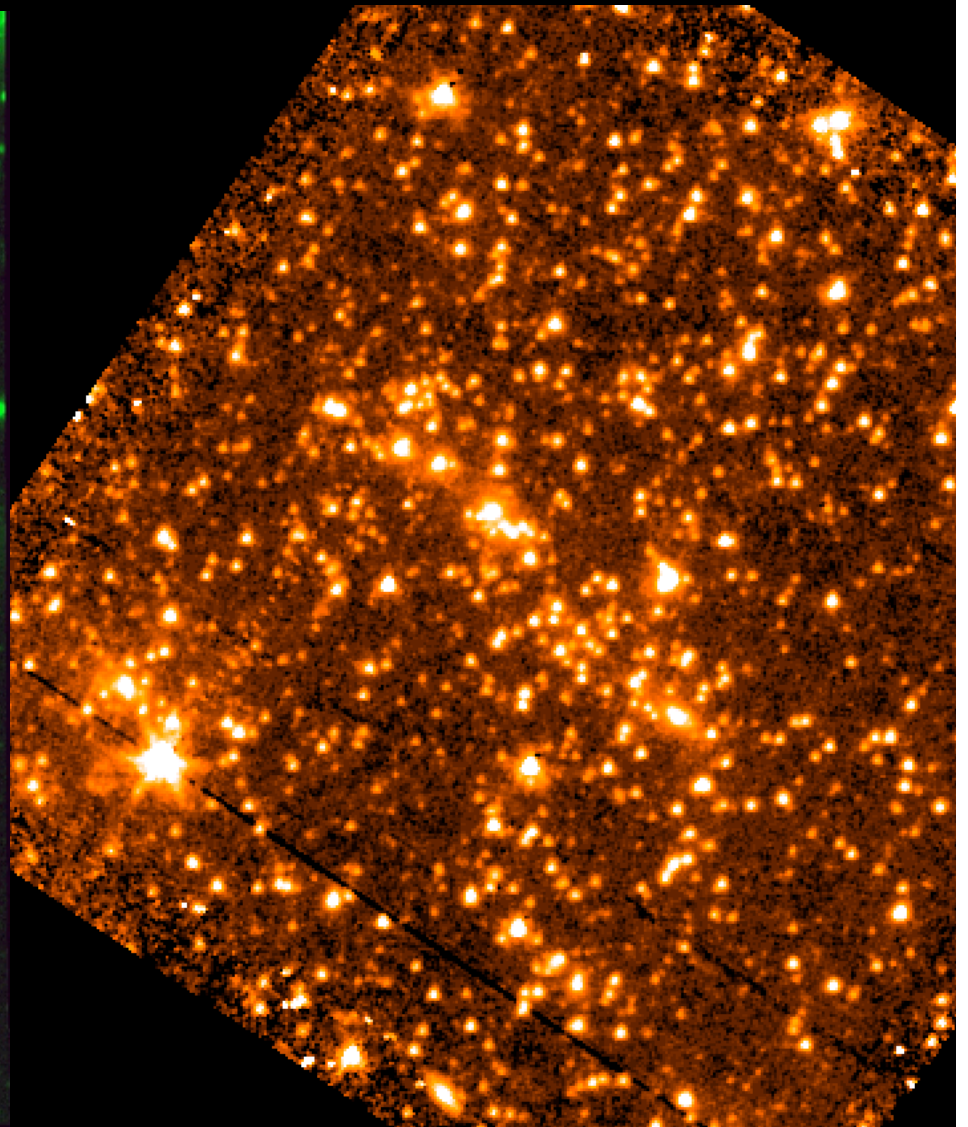
Cape Canaveral, Florida



CI 0152-13 at $z = 0.83$ in vri



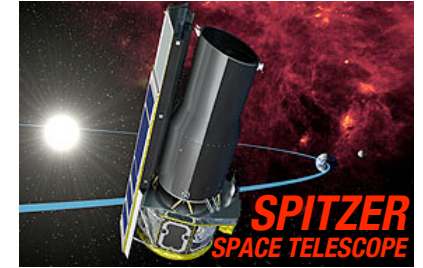
vri image from Piero Rosati, VLT



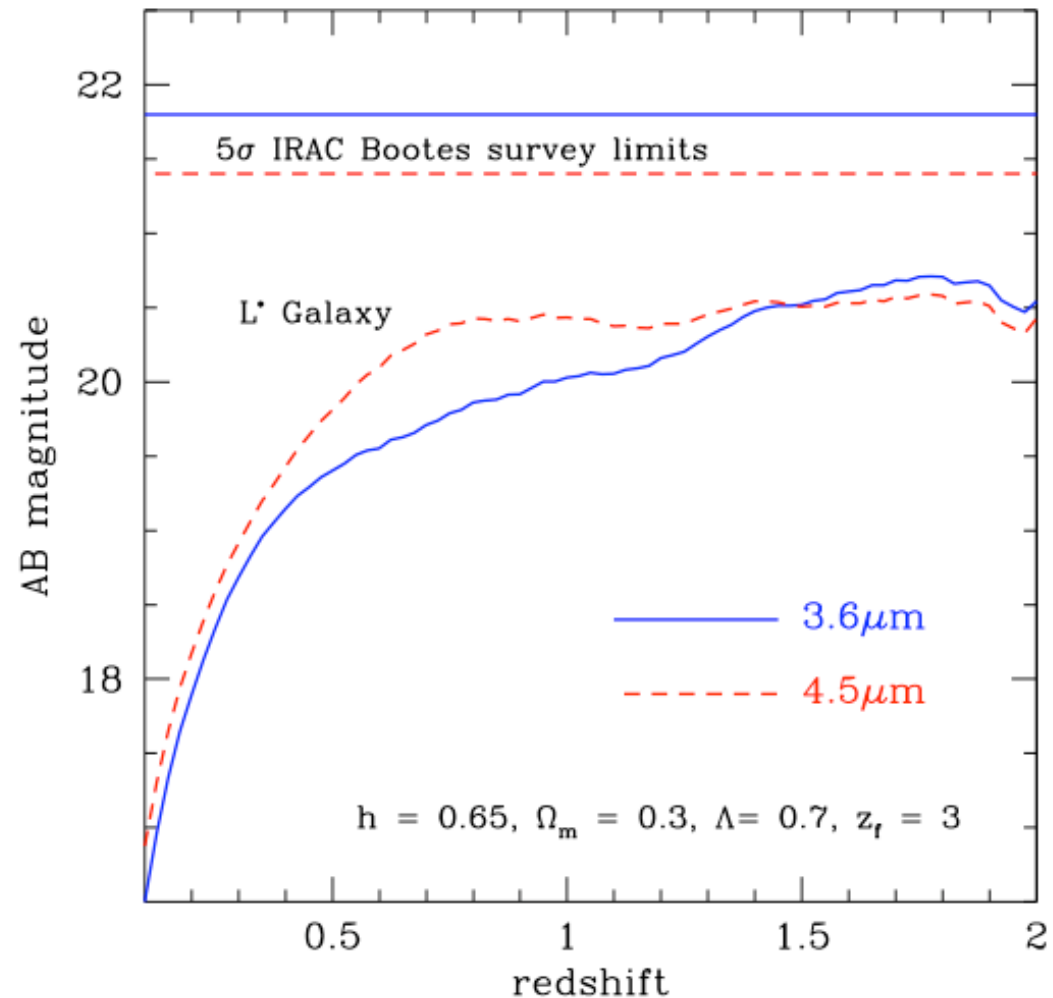
3.6 micron IRAC image, 5 x 200 sec



IRAC Shallow Survey



- Survey limits are pre-launch expected; actual are ~ 0.1 mag more sensitive
- $\sim 370,000$ $3.6\mu\text{m}$ sources in 62 hours IRAC observing
- Predictions extrapolate measured K ($2\mu\text{m}$) luminosity in $z = 0 - 1$ clusters to $4.5\mu\text{m}$ and $z=2$, using models which also fit the color-magnitude relation.
- We hope to find ~ 100 $z > 1$ clusters in the shallow survey



3.5 degrees

NGC 5646

The IRAC Shallow Survey
4.5 micron image
8.5 sq degrees
in NDWFS Bootes
3 x 30 sec/position

N

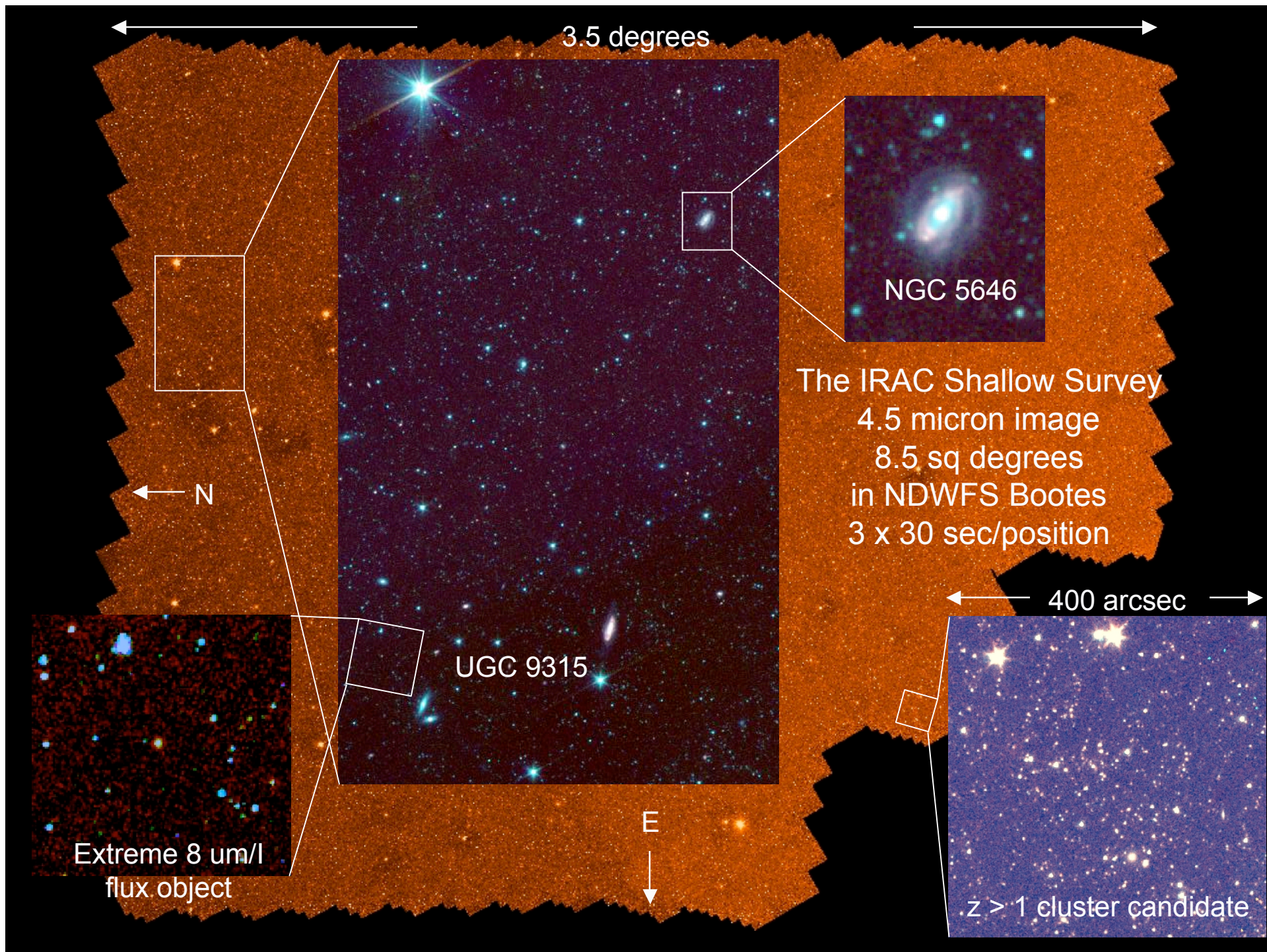
UGC 9315

400 arcsec

Extreme 8 um/I
flux object

E

$z > 1$ cluster candidate

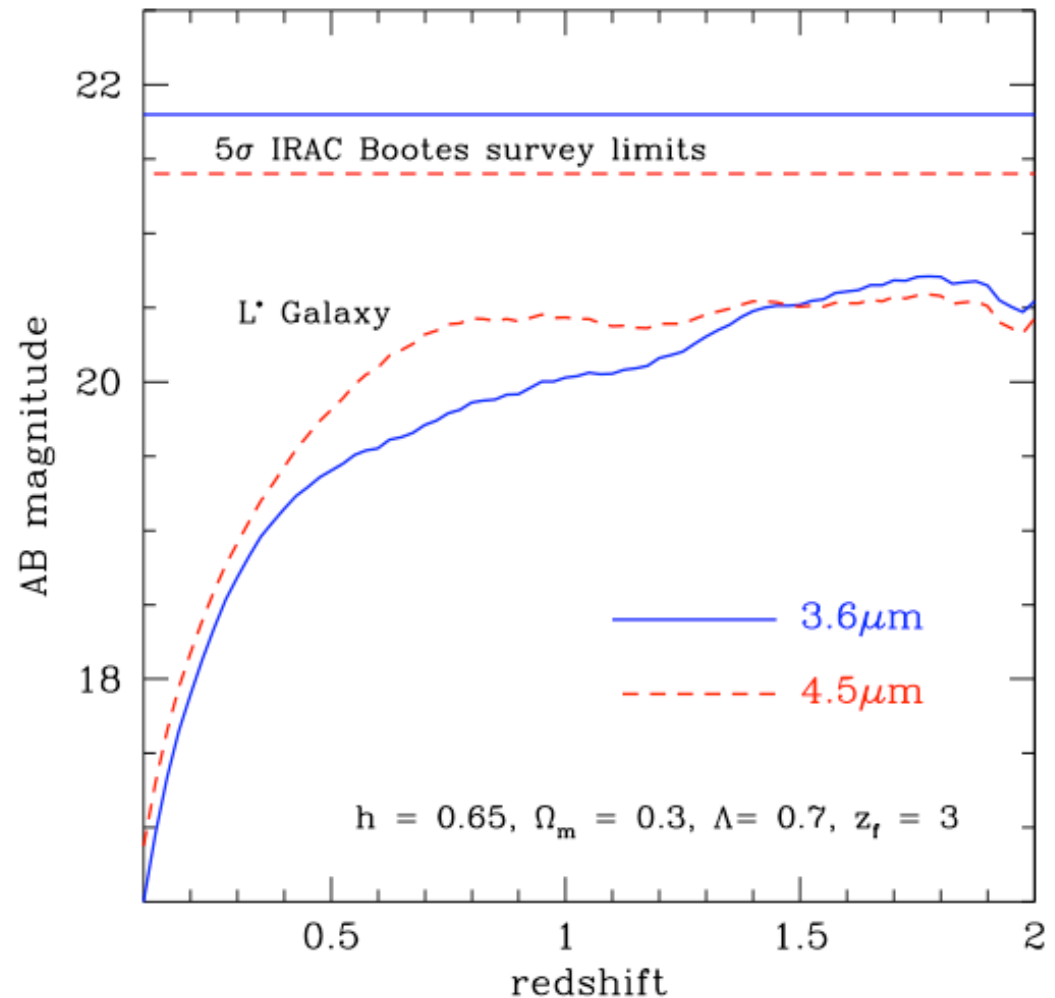


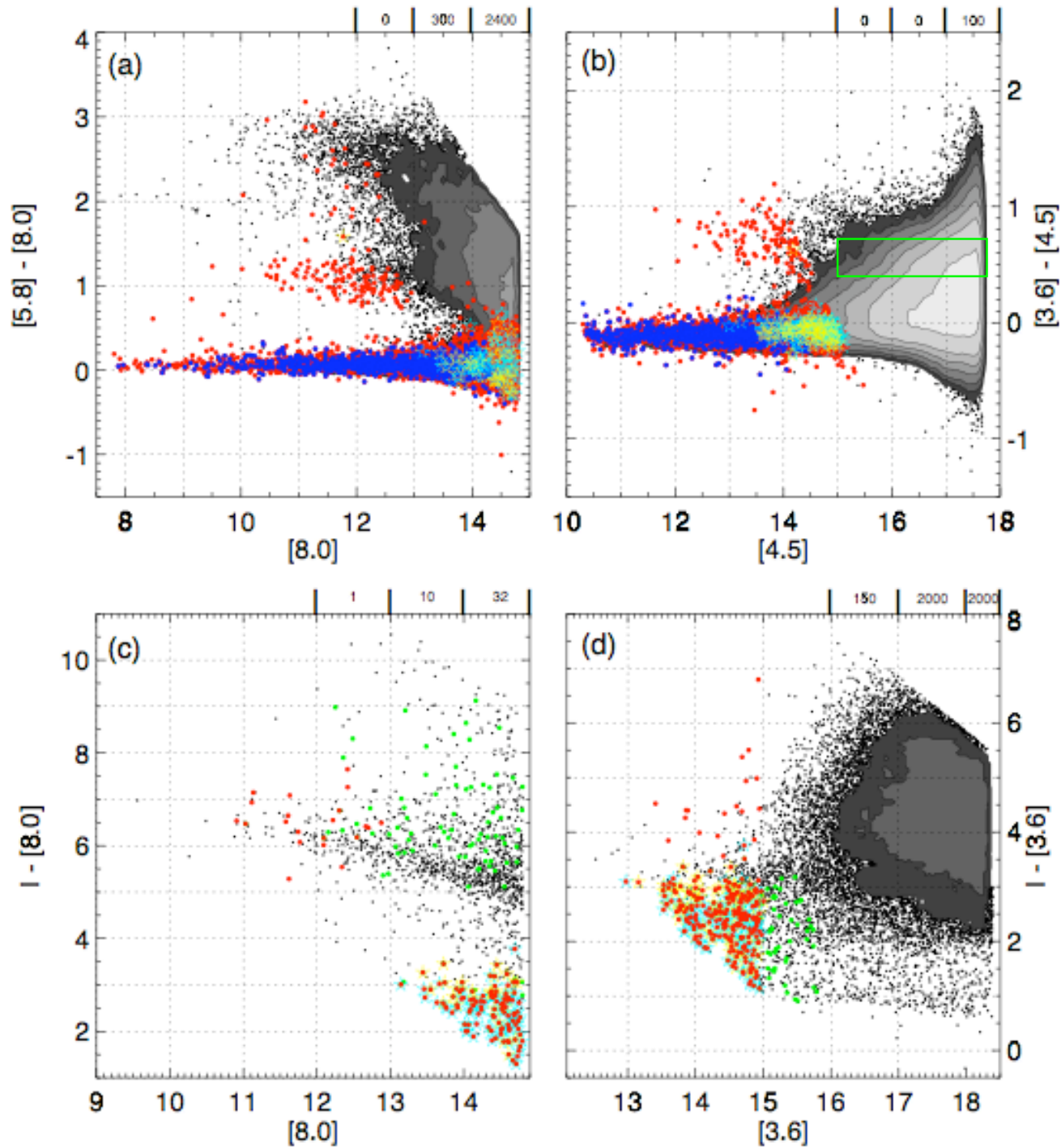


Initial Search for $z > 1$ Clusters



- Find 2 x 2 arcmin boxes with highest density of sources with:
 - $0.4 < [3.6] - [4.5] < 0.72$
 - $15 < [4.5] < 17.7$
 - $(18.2 < [4.5]_{AB} < 20.9)$
- 31,173 boxes on 1 arcmin centers with $< 5\%$ missing data
- Median of 5 qualifying sources/box
- 37 densest boxes have 24 to 18 sources
- Many of these boxes overlap
 - 20 distinct fields



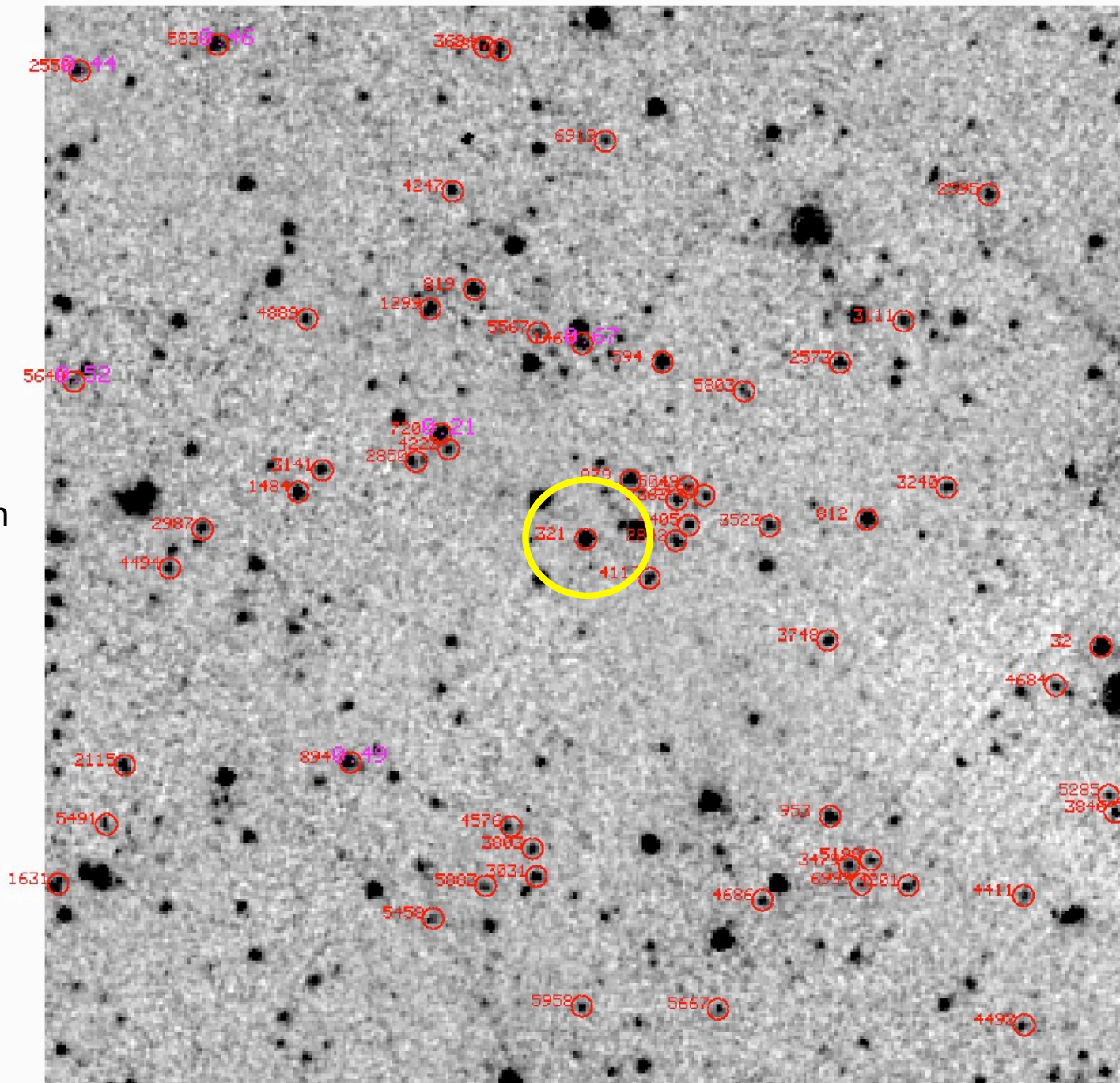




4.5_MICRON

CLUSTER_CANDIDATE : 31

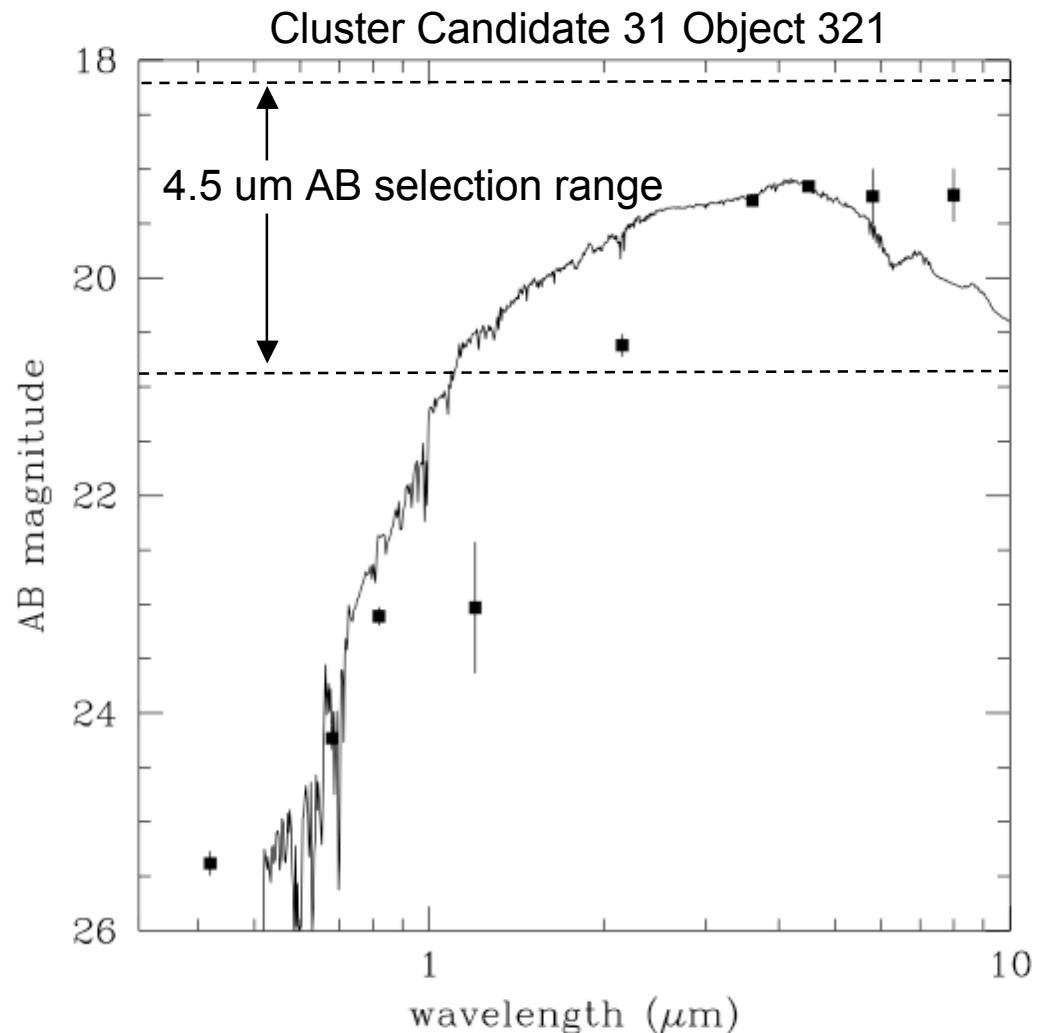
5 arcmin
FOV



Typical $z > 1$ Candidate SED

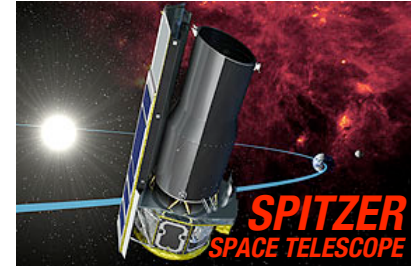


- Typical (really!) example
- SED data from
 - IRAC Shallow Survey
 - FLAMEX
 - NDWFS
- PE $z_f = 3$ model for illustration
 - Normalized at 4.5 μm
 - Observed at $z=1.5$
 - No attempt to fit here
- Suggests $z > 1.5$
- $[3.6] - [4.5]$ criterion not particularly narrow in z
- Need to do phot- z 's!





Summary



- The IRAC shallow survey detects L-band sources $\sim 9,000$ times faster while reaching ~ 5 times deeper than the deepest previous work with Keck
 - Advantage increases at longer wavelengths
- Depth is sufficient to select passively evolving cluster galaxies to $z = 2$
- Photometric redshift fitting using IRAC, NDWFS and FLAMEX data underway
- Spectroscopically confirmed $z > 1$ clusters will test the red spike model for cluster galaxy formation