Ly-α sources and ACS: GRAPES and PEARS

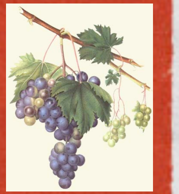
N. Pirzkal, S. Malhotra, Rhoads J., C. Xu, A. Straughn and the GRAPES and PEARS teams

GRAPES:

Grism-ACS Program for Extragalactic Science

PEARS:

Probing Evolution and Reionization Spectroscopically



GRAPES:

Grism-ACS Program for Extragalactic Science

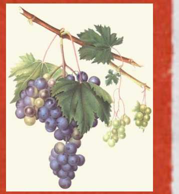
- HUDF observed for 40 orbits using the ACS WFC Grism mode (Pirzkal et al. 2004)
- Most extensive use of the Grism mode with ACS
- 4 position angles to help with contamination
- Good continuum S/N to $I_{AB} \sim 27.2$ (2 magnitude deeper than ground based observations)
- 1500 useful spectra, or about 15% of all sources in the HUDF catalog
- Efficient emission lines detection down to 5×10^{-18} erg/s/cm^2/Å

GRAPES:

Why the HUDF?

- Deepest field observed with ACS and HST, 11 arcmin^2
- z~29 limiting magnitude for point sources
- ~10000 sources in catalog
    - HST/ACS: B,V,i,z
    - HST/NICMOS: J,H
    - VLT/ISAAC: J,H,Ks
    - Spitzer/IRAC: 3.6μm, 4.5μm, 5.8μm, 8.0μm

GRAPES:



Why using slitless spectroscopy?

- Selecting high redshift objects using colors can be misleading...
- Slitless spectra offer un-interrupted coverage at ~ $4<z<6$
- No pre-selection of target required

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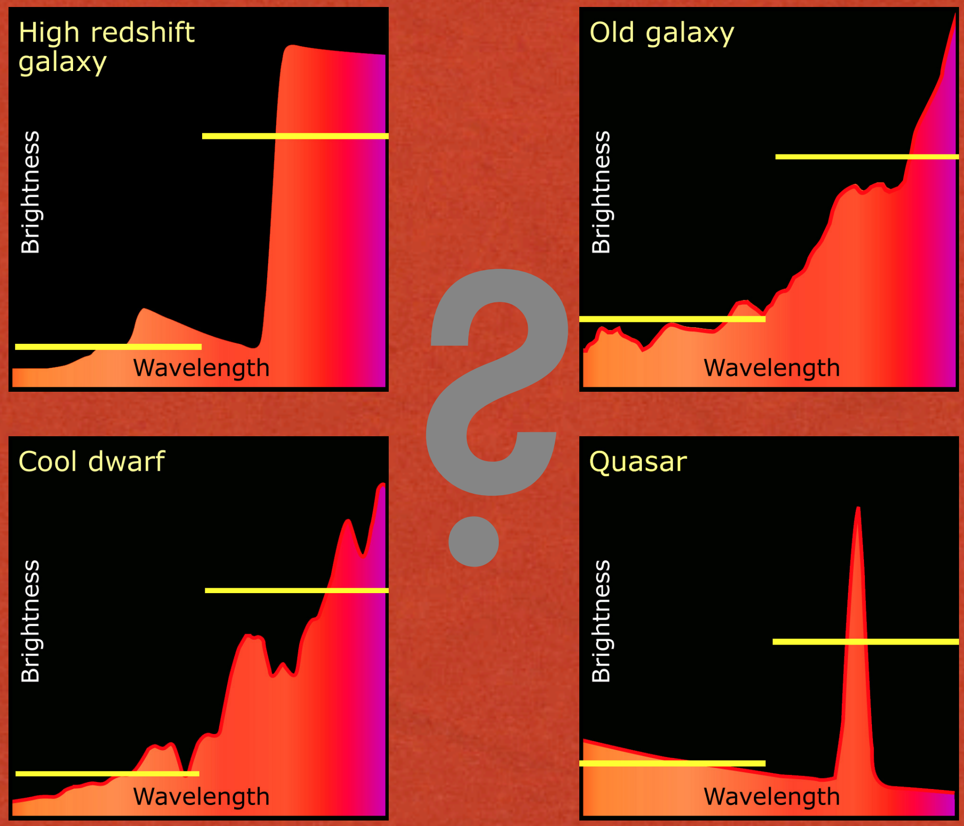
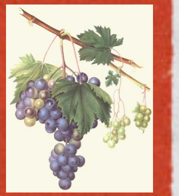
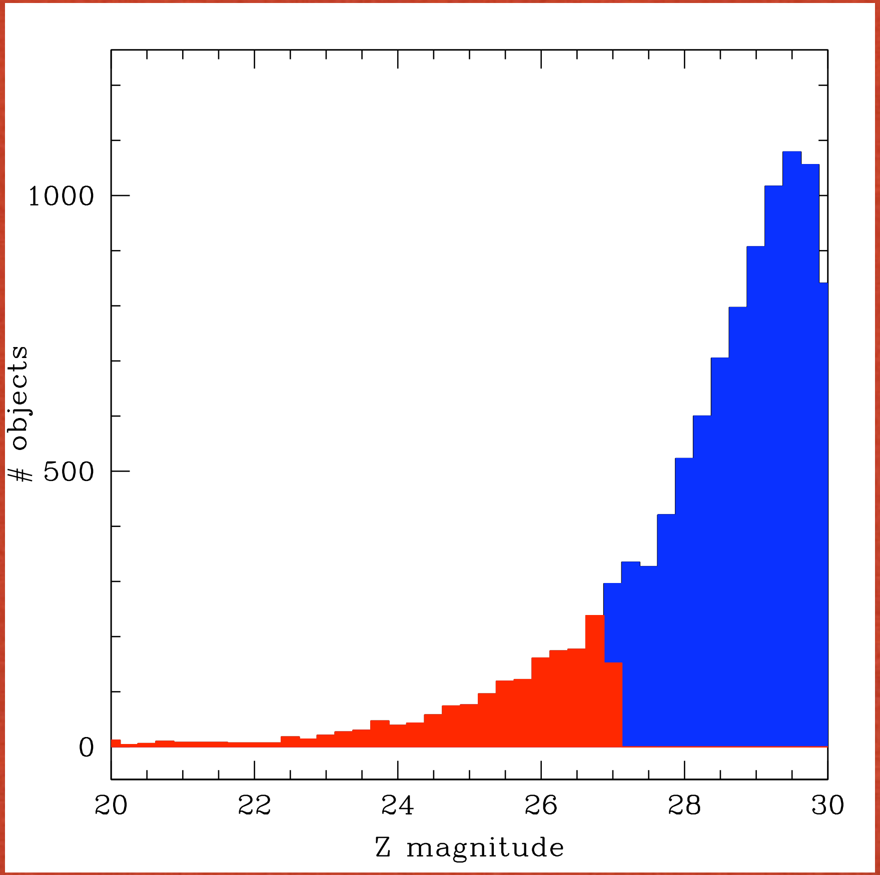
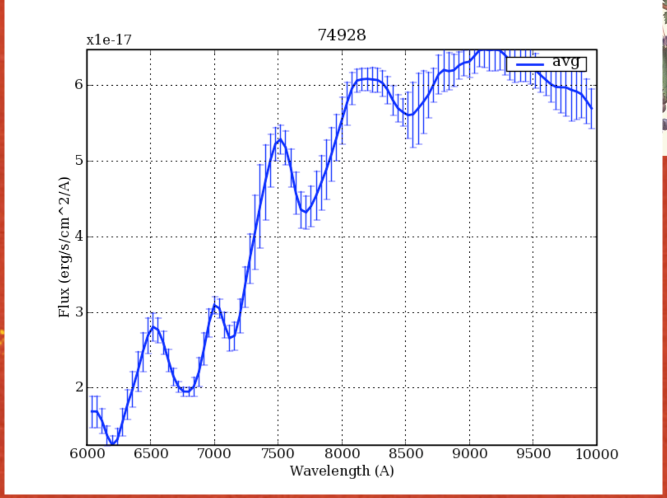


GRAPES: Results



- 1500 useful spectra (15% of HUDF sources)
- Good continuum S/N to $I_{AB} \sim 27.2$
- Spectoscopically identified:
    - Stars (Pirzkal 2004)
    - Old pop. gal. (Daddi 2005)
    - eGRAPES/LCBGs (Pirzkal 2006)
    - High-z Ly-α gal. (Pirzkal 2007)

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x1e-17
avg
Flux (erg/s/cm^2/A)
Wavelength (A)
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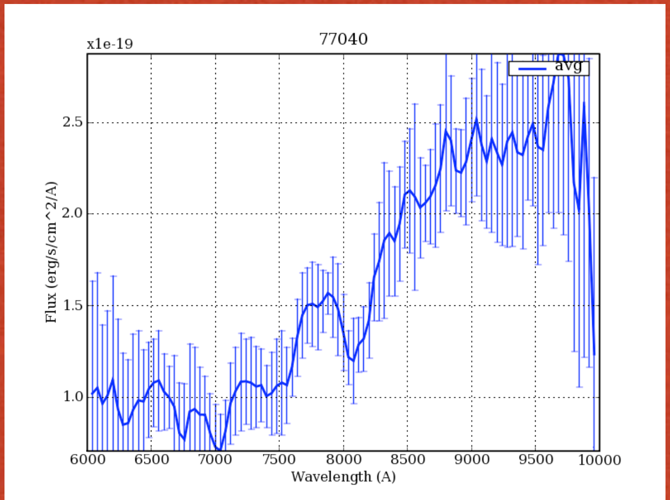
2 3 4 5 6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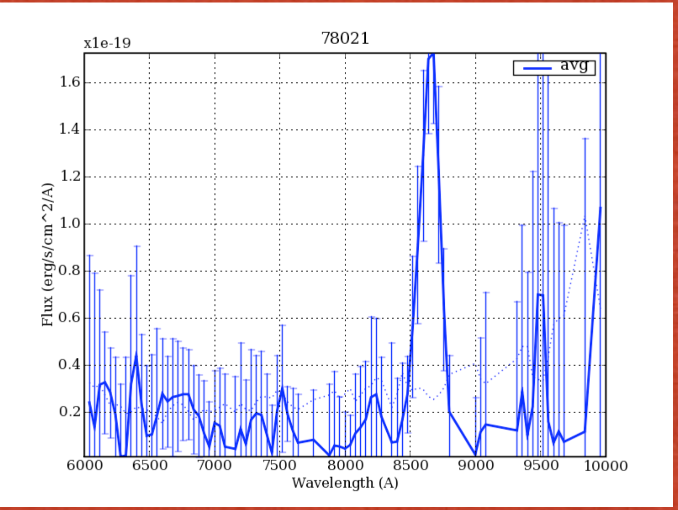
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Flux (erg/s/cm^2/A)
Wavelength (A)
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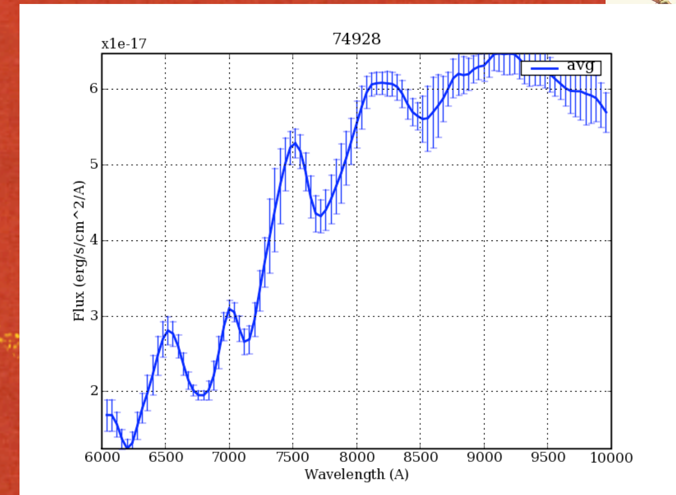
M Dwarf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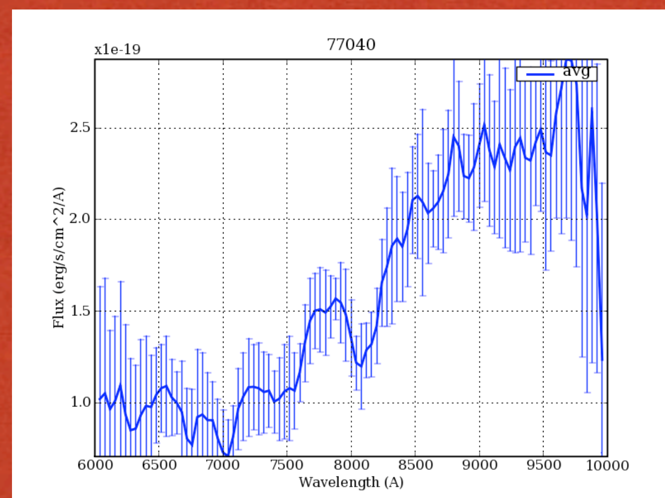
Old z=1.9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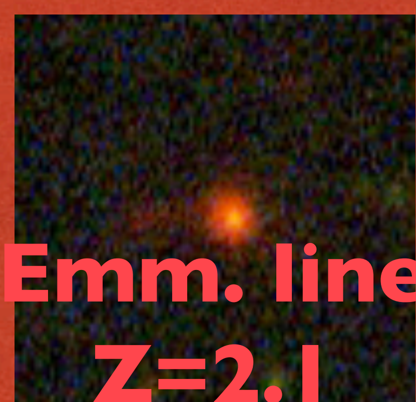
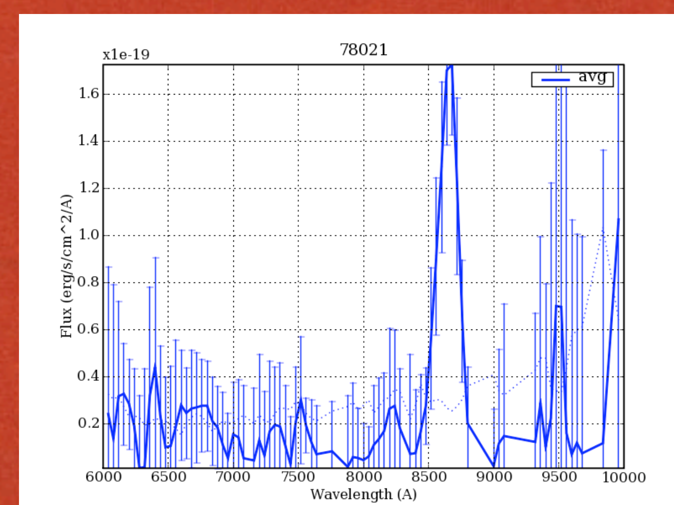

Emm. line
Z=2.1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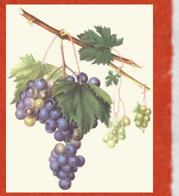
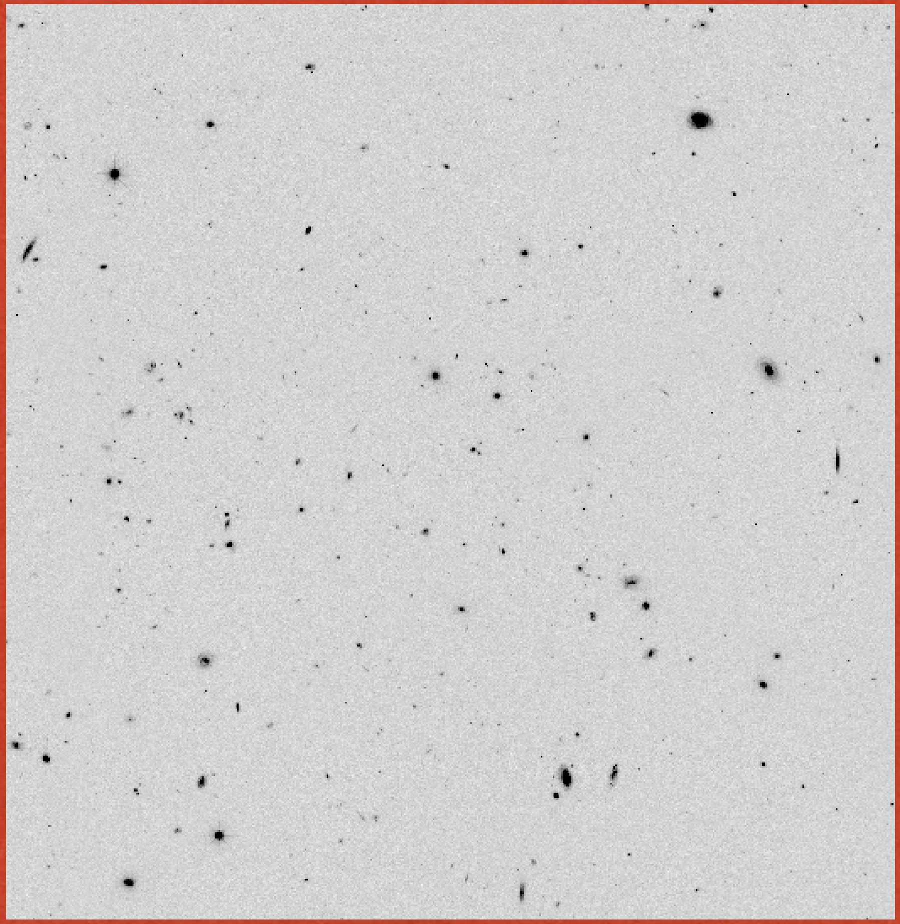
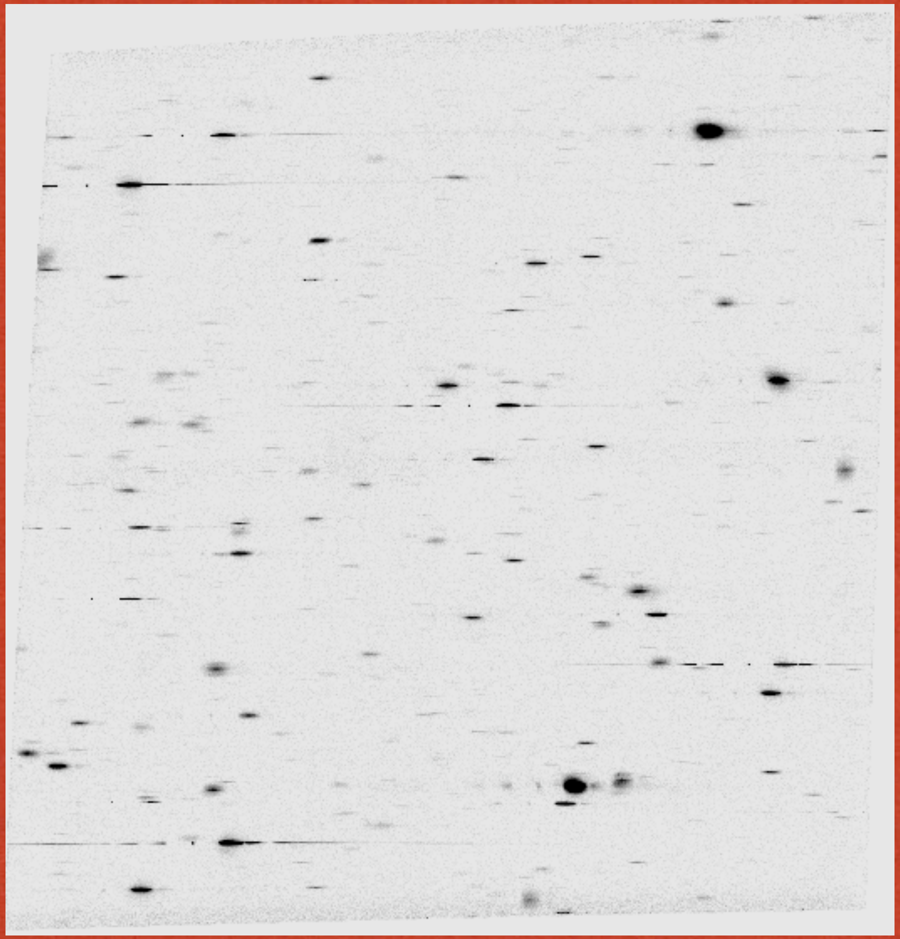
GRAPES:



Examples





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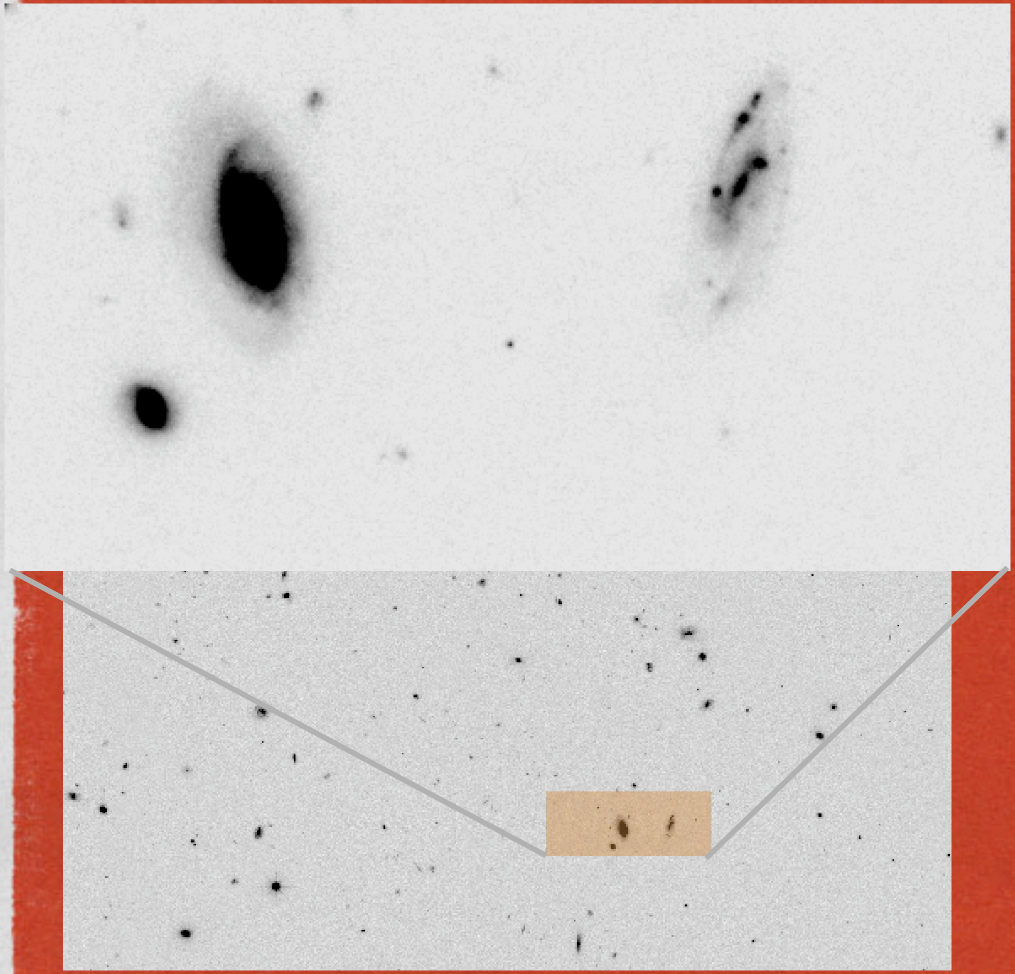
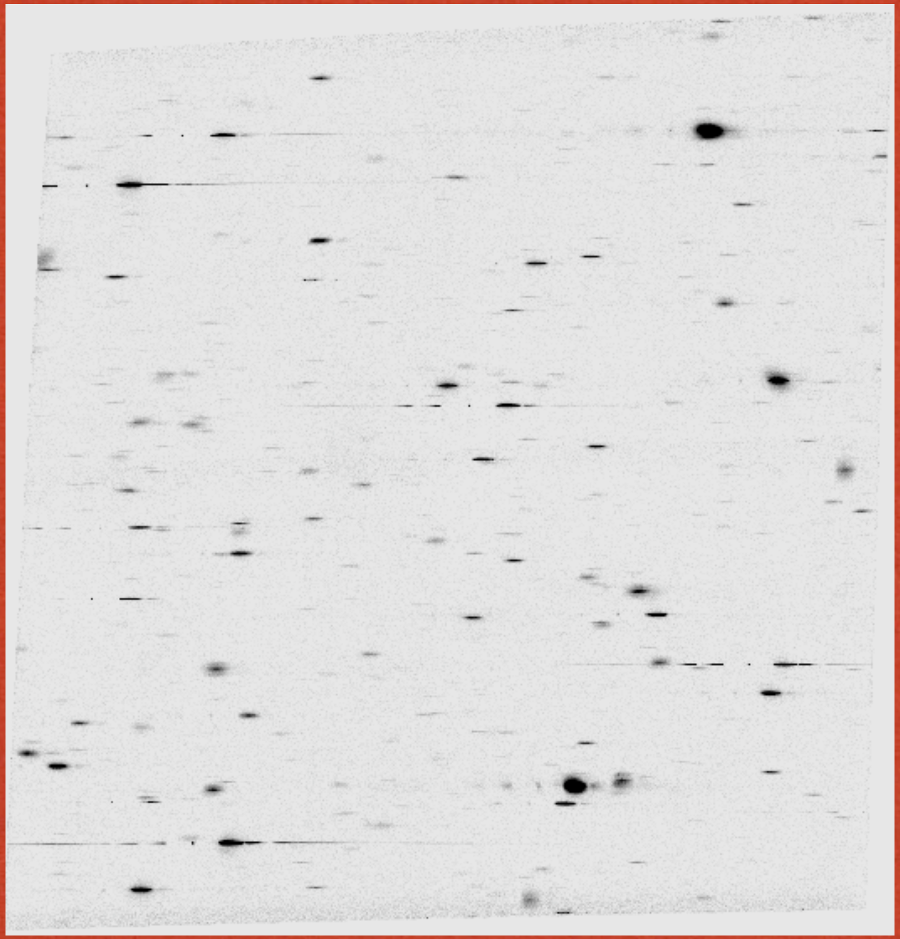
Examples





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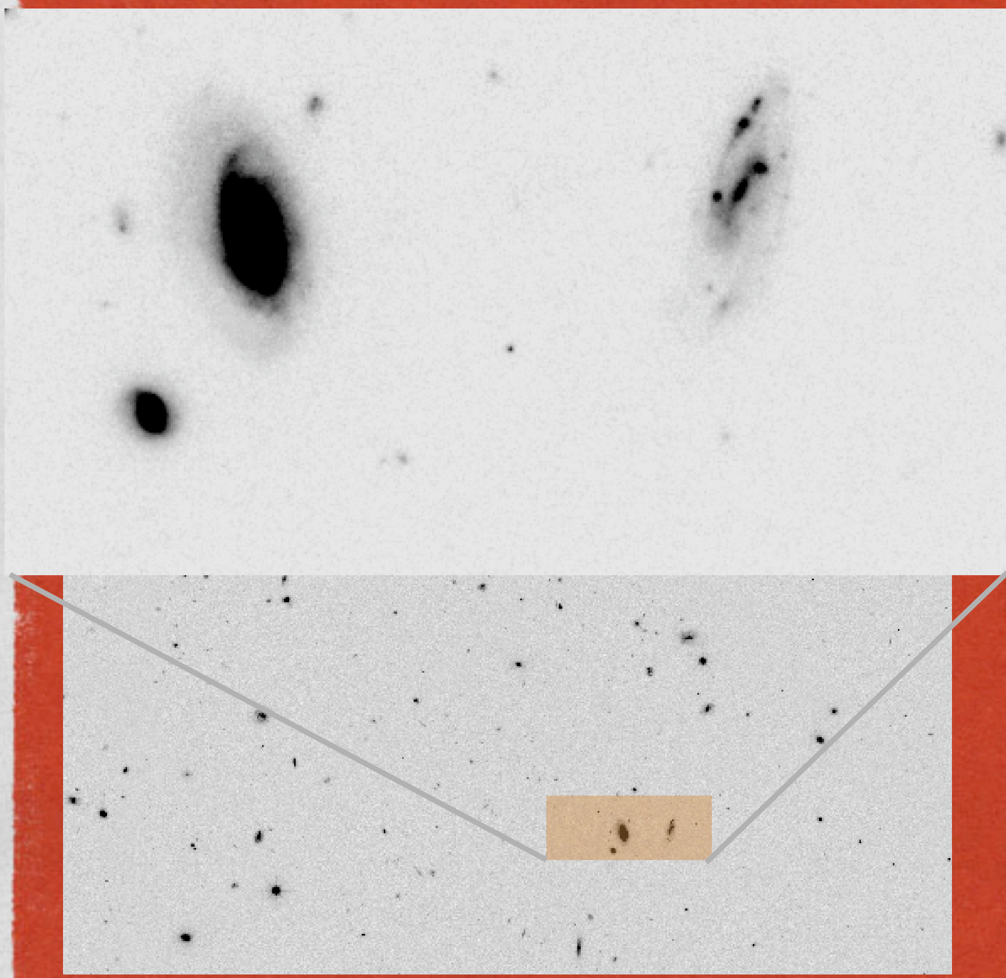
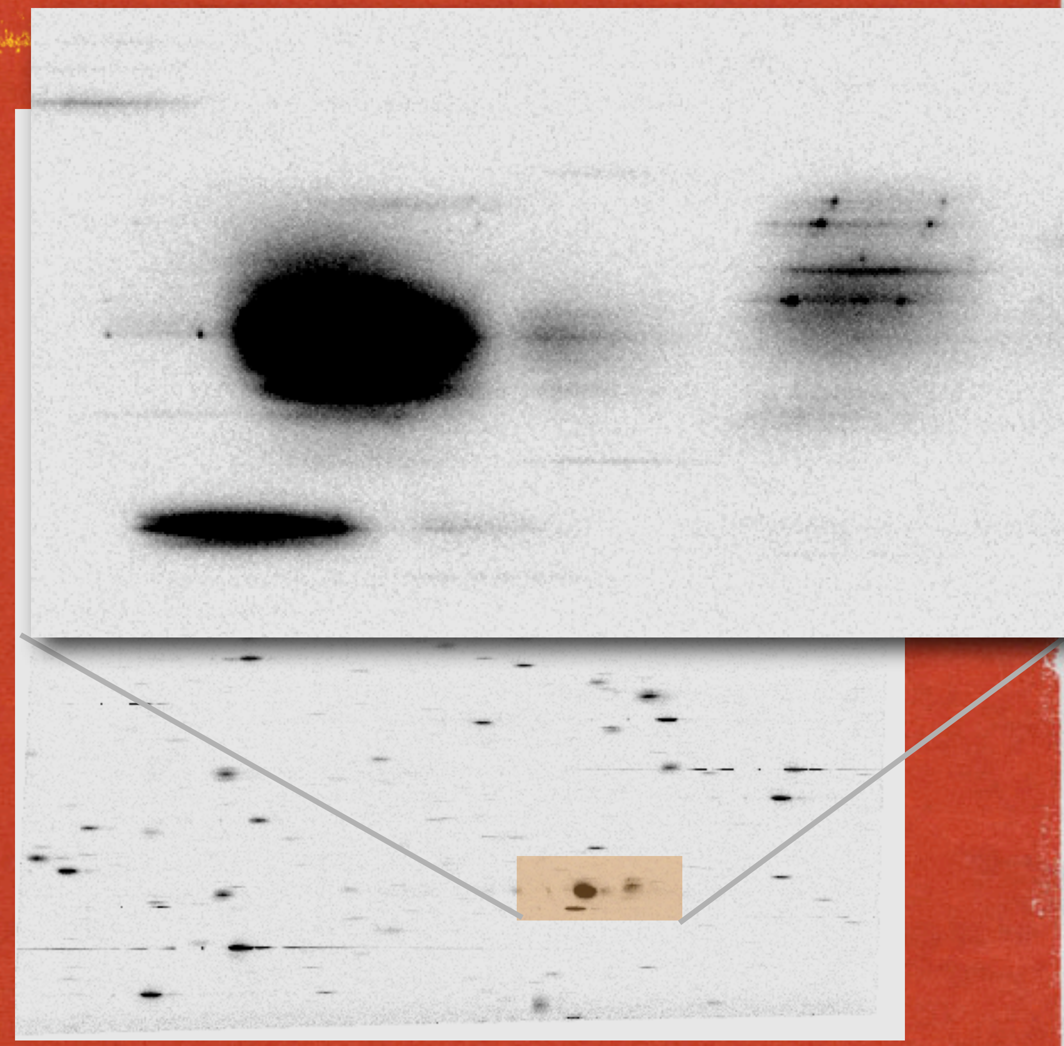
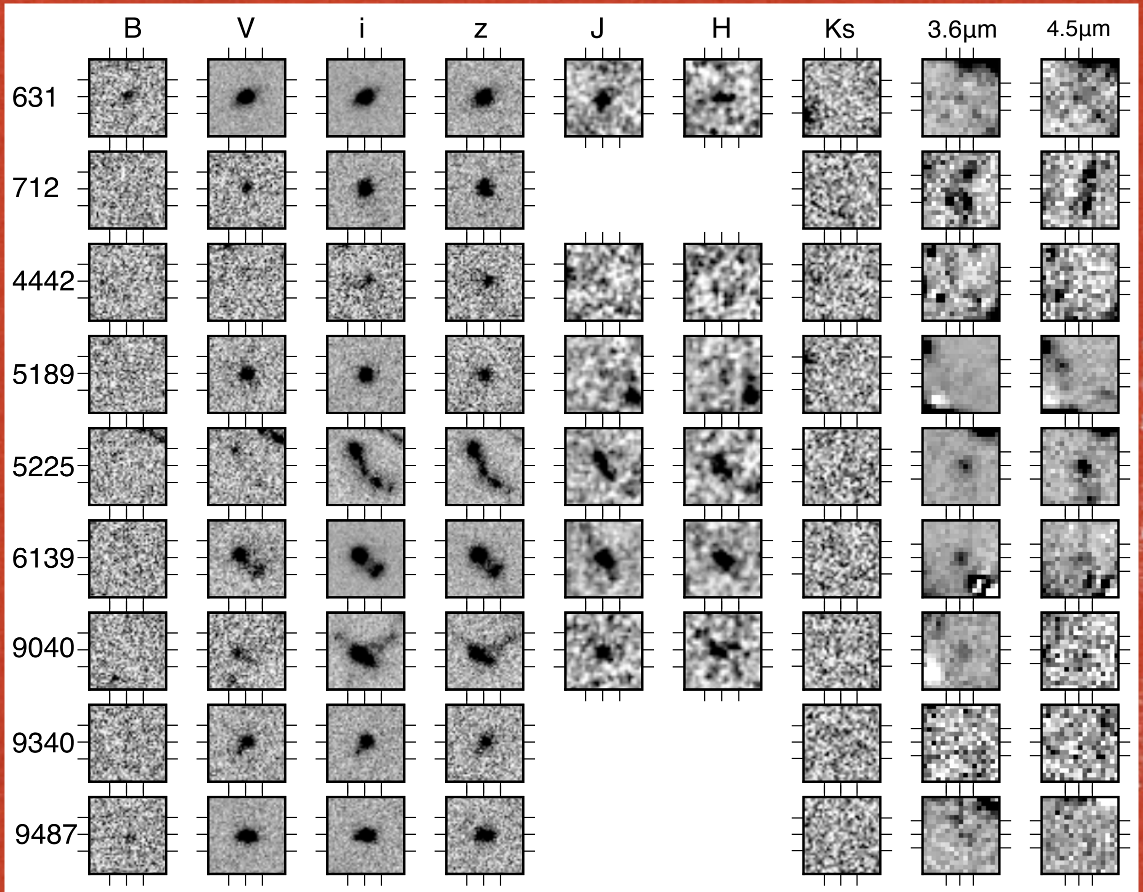




GRAPES:
Ly-α sources

- $4.0 < z < 5.7$
- no known X-ray within 5” (not AGNs)
- Faint: $25.6 < m_z < 28.4$
- Small: $R_{1/2}$=0.92±0.50 kpc (0.17±0.07”)
- Concentrated and symmetric (CAS)
- Three exceptions:
  - Little larger: $R_{1/2}$=1.56±0.27kpc
  - More asymmetric
  - Potentially interacting/clumpy objects



GRAPES Ly-α sources color

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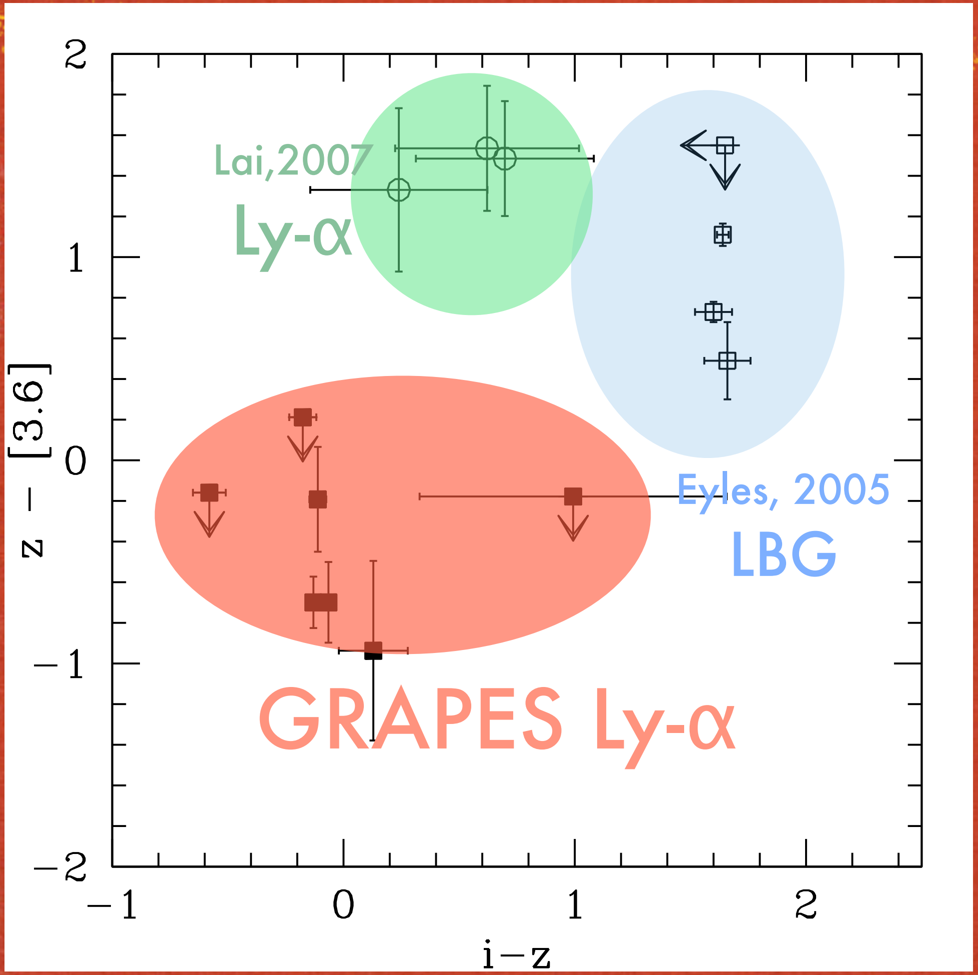

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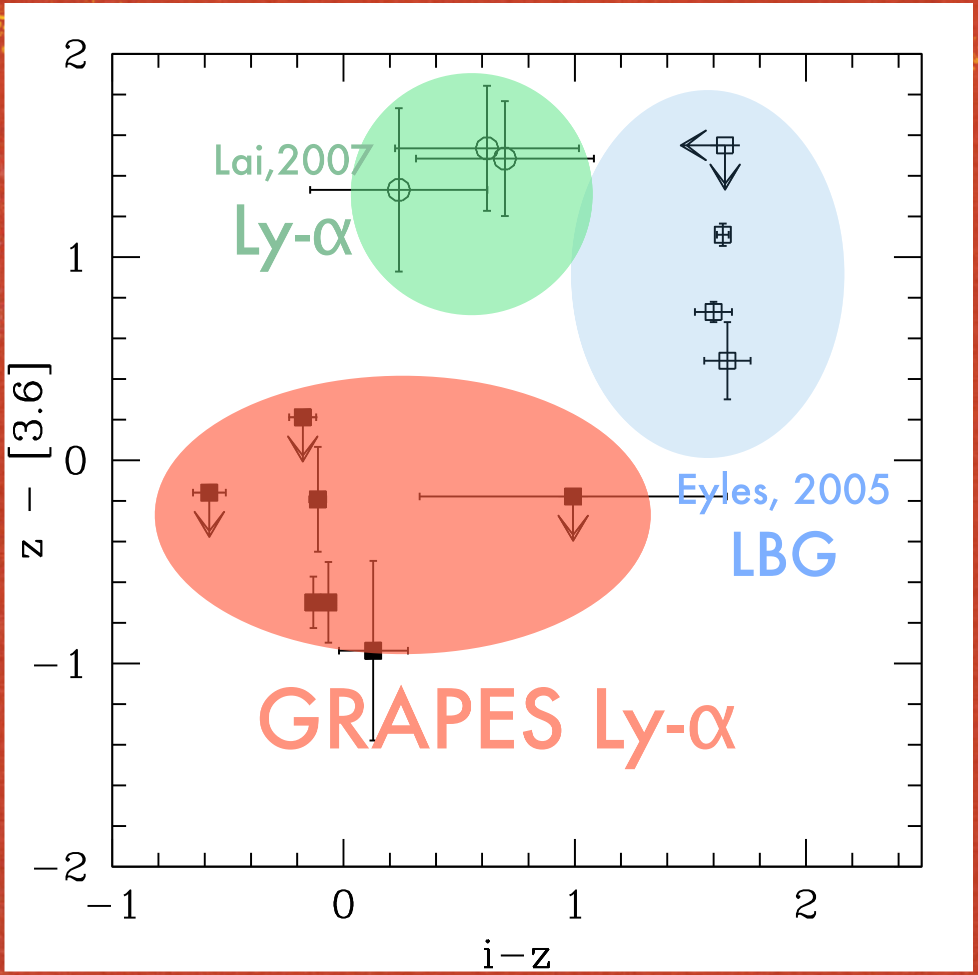
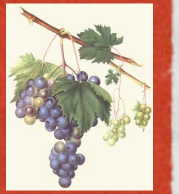
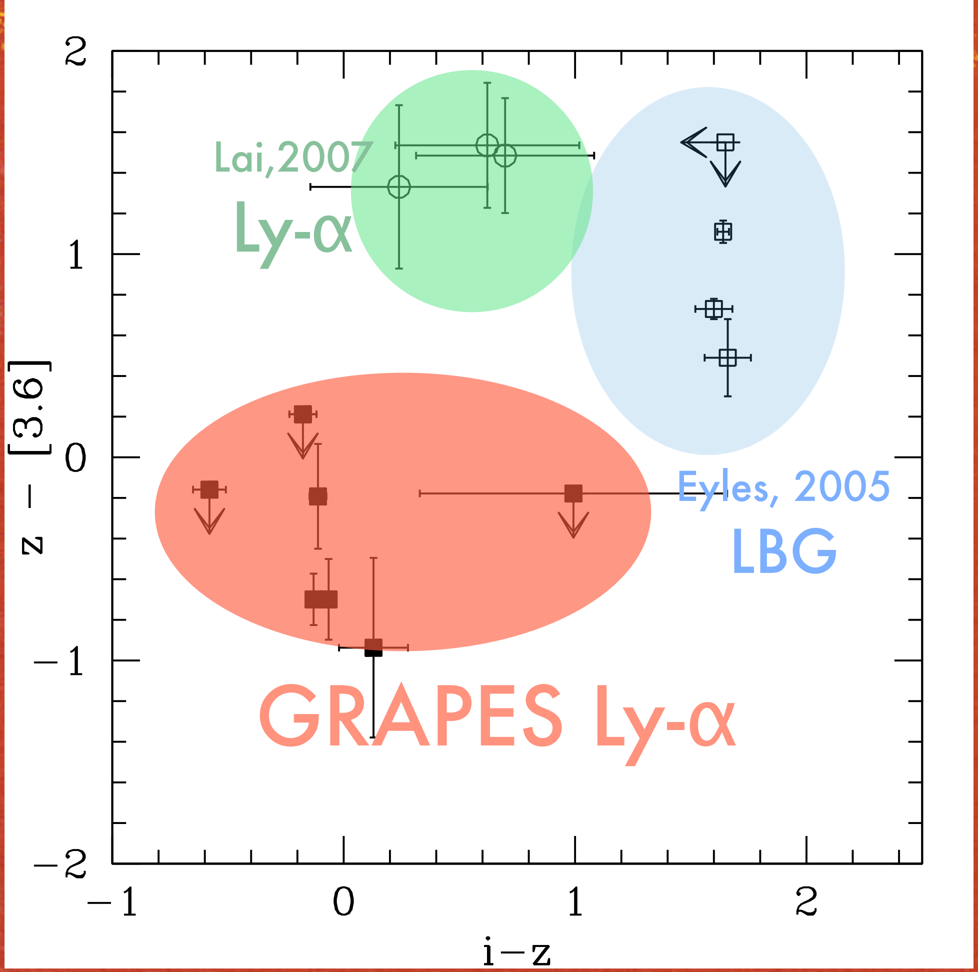
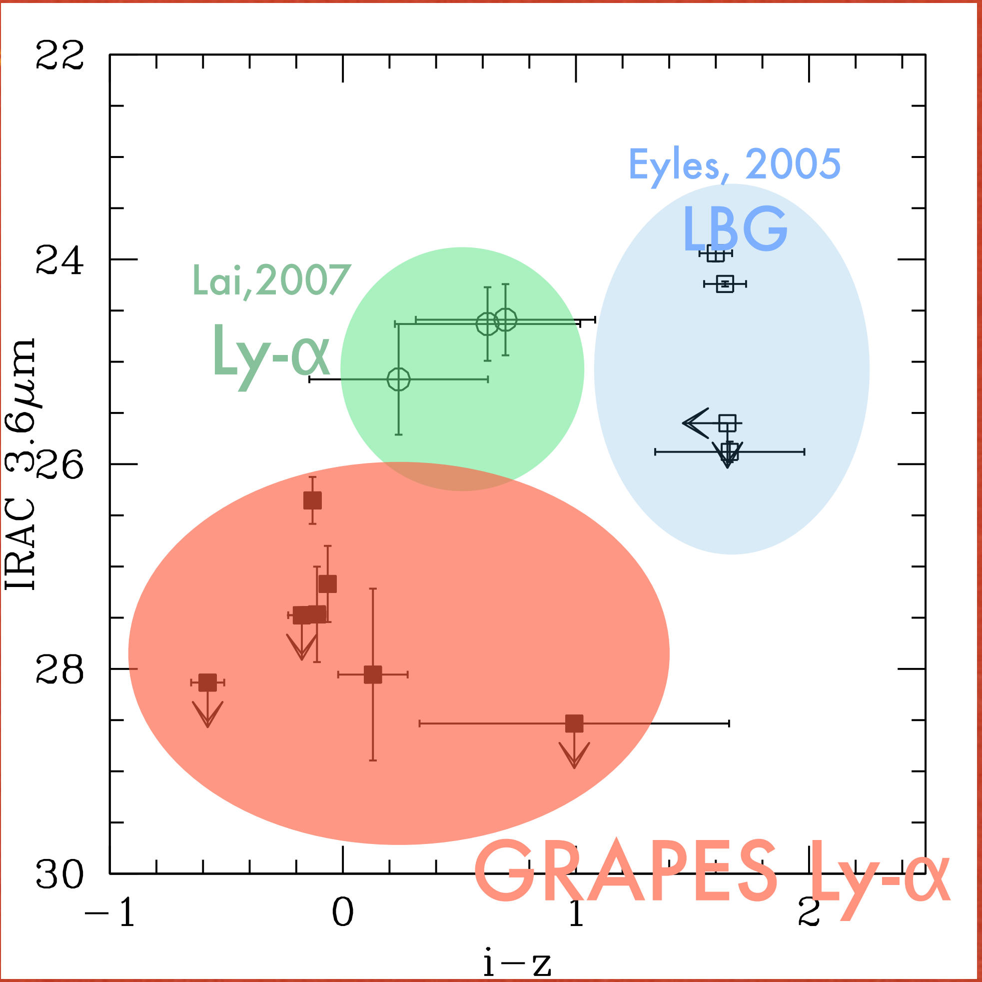


Bluer. Younger?

GRAPES Ly-α sources color







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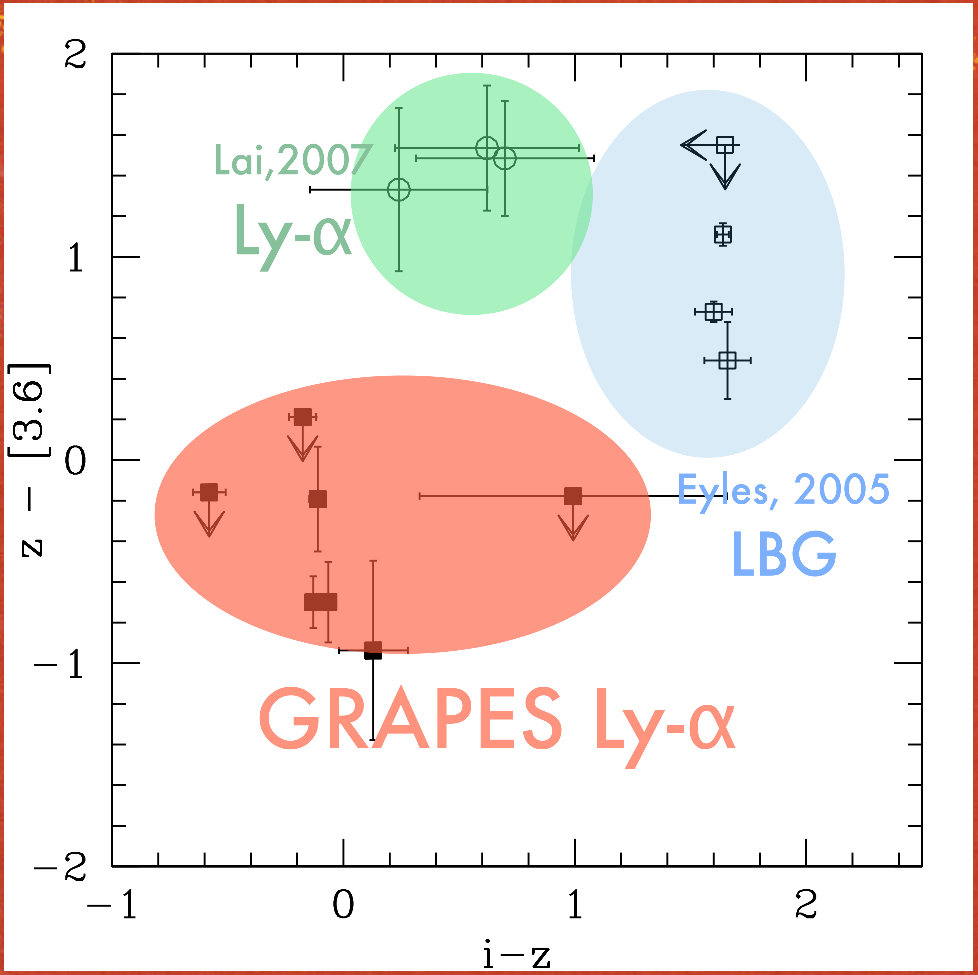
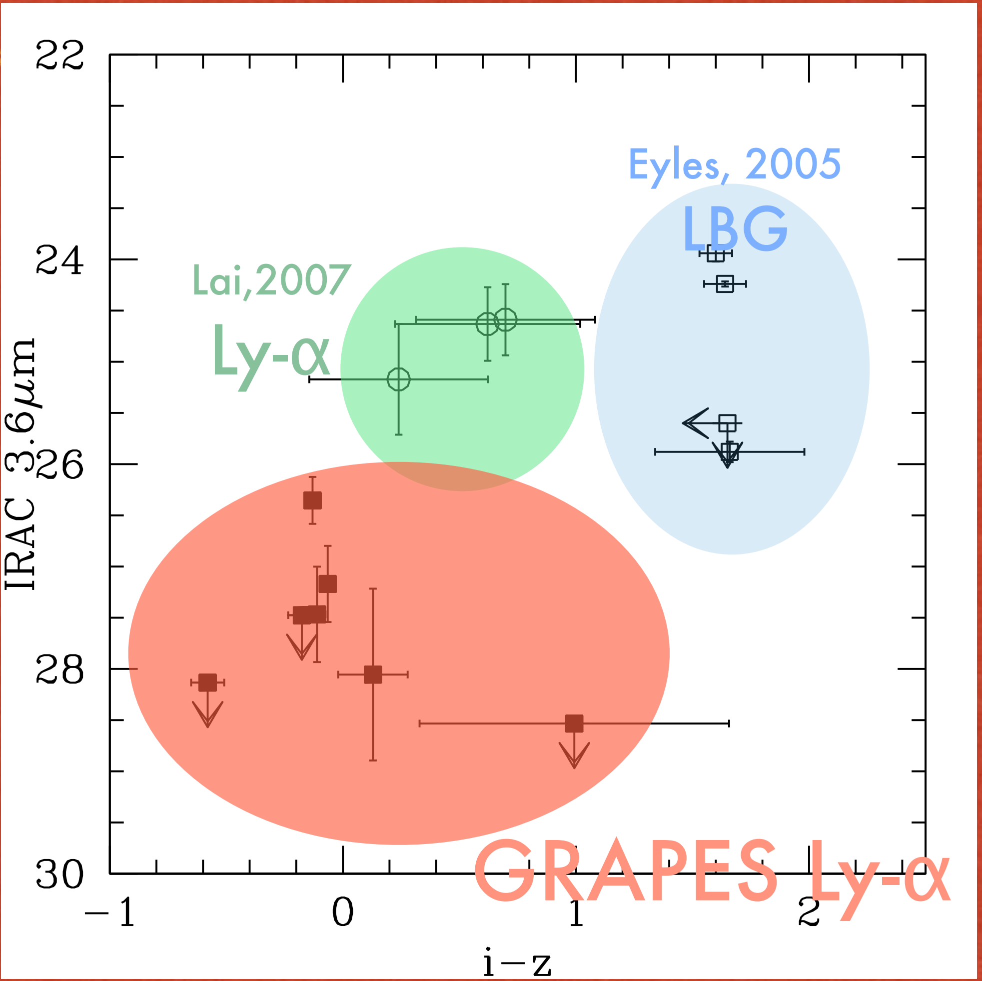
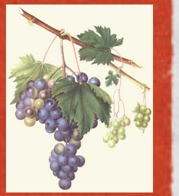




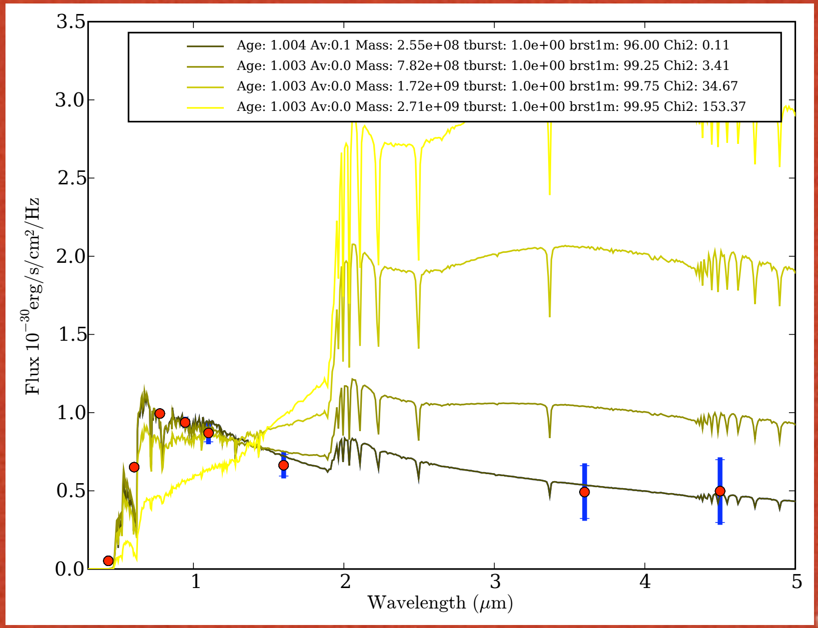
Bluer. Younger?

Fainter. Lower masses?

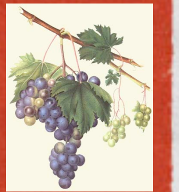
GRAPES Ly-α Sources SED Fitting



- Goal: Set upper limits to the stellar mass of these sources
- BC03 models with IGM absorption
  - Age (5Myr--1.2Gyr)
  - Metallicity (all 5 values from BC03)
  - Calzetti Extinction law (Av=0..3.0)
  - Three star formation histories:
    - Single instantaneous burst (SSP)
    - Single exponentially decaying burst (EXP)
    - Double instantaneous bursts (SSP2)

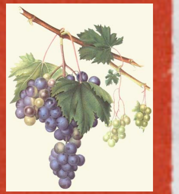


SED Star Formation Histories



- SSP Model: A single, instantaneous burst. Star formation occurs once and the stellar population subsequently evolves passively.
- EXP: A single burst of star formation, but not instantaneous. Star formation decays with a e-folding time of τ. As a galaxy evolves, an increasingly larger fraction of its stars get old.
- SSP2: Two bursts. This model is designed to allow for the larger possible mass because there is a possibility of having a very large number of stars in the form of fainter, older population. In this model, the rest-frame UV light is produced by a small fraction of young stars.

But... SED fitting is complicated by...

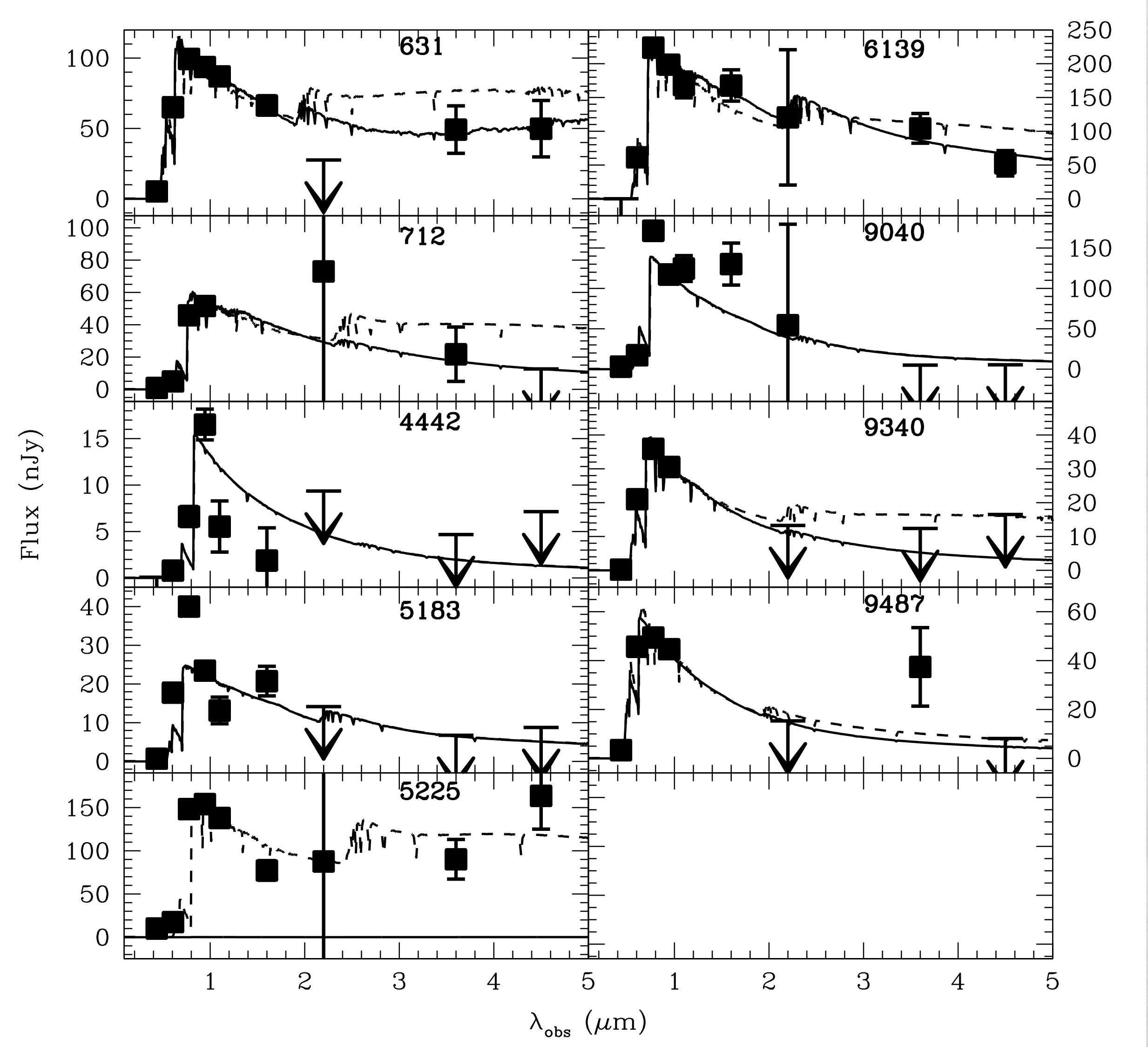


- Some of the sources were not detected in the IRAC bands. We can/ need to use these non-detections as upper limits.
- IRAC observations have a relatively low resolution and contamination by neighboring objects can be a problem (See A. Gonzales talk this morning). This leads to an over-estimate of the rest-frame optical flux from these objects, and therefore of their mass estimates.
- Light originating from neighbors fitted using generalized Sersic profiles (using GALFIT) and subtracted.
- Objects masses were computed using detected bands.
- But, models violating the non detection upper limits (at the 2σ level) were rejected.

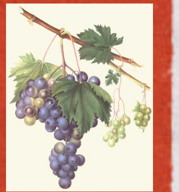
IRAC data Photometry

GRAPES Ly-α properties

- **All SFR scenarios lead to:**
  - Young ages: few 10^7 years
  - Low masses: 10^7 - few 10^8 $M_\odot$
  - Moderate to no extinction
  - Low metallicity
  - SSP2 SFH leads to higher masses, but still only up to a few 10^8 $M_\odot$



GRAPES Ly-α density and SFR

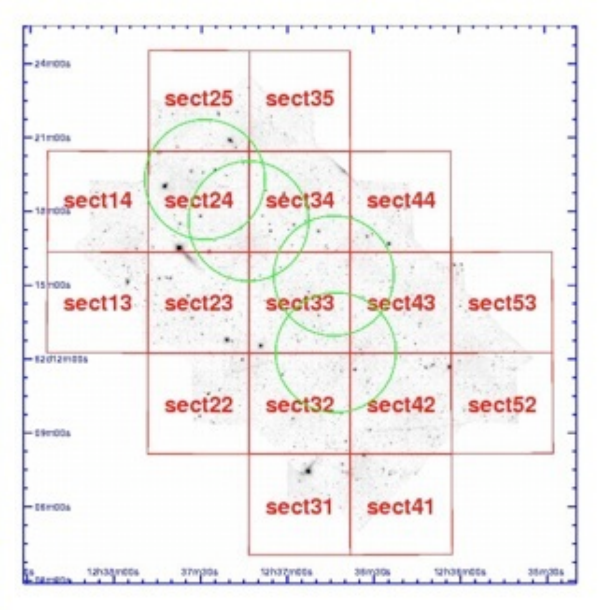


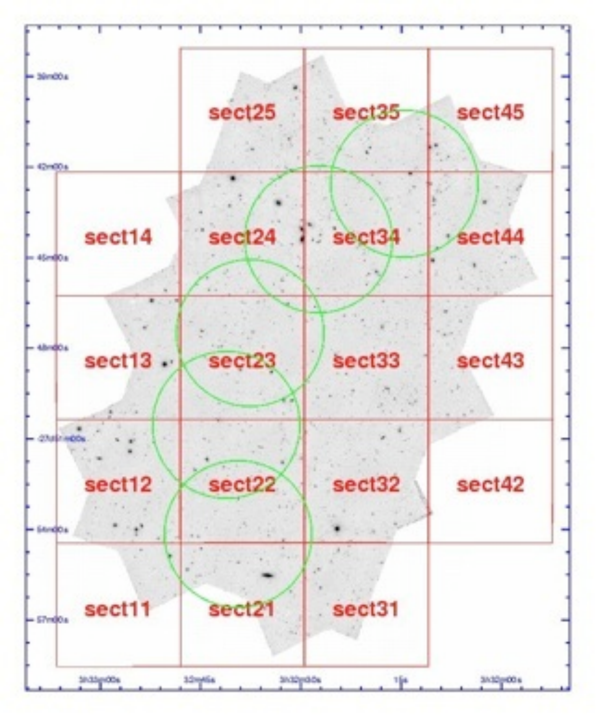
- The computed density of these $4.0<z<5.7$ objects is $\sim 1.25\times10^{-4}$ Mpc^{-3}
  - Density consistent with $z=3.1$ Ly-α (Gawiser 2006).
- Star formation rates (Ly-α luminosities): $7.8 \pm 3.2\ M_{\odot}\ \mathrm{yr}^{-1}$
  - SFRs high enough to allow these objects to have assembled their masses in a few 10^6 years.
- Mass estimates consistently lower than a few $\times10^8\ M_{\odot}$
  - x10-x100 less massive than typical LBGs at high redshifts (Eyles 2005).
  - x5-x10 less massive than previously, brighter, identified Ly-α sources
- These are members of an exisiting population of low mass, young, star forming galaxies at $z=5$, previously left unobserved.

PEARS:

Probing Evolution and Reionization Spectroscopically

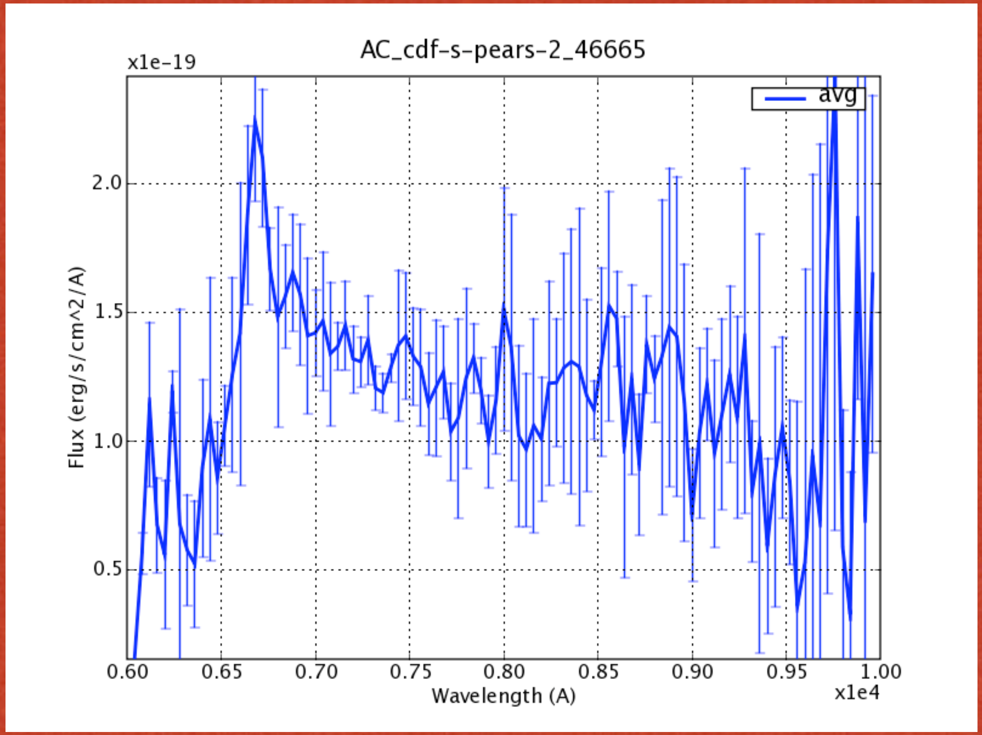
- A shallower but wider version of GRAPES
- 9 ACS fields observed using:
  - 4 in GOODS-N (20 orbits)
  - 4 in GOODS-S (20 orbits)+ HUDF (40 orbits)





PEARS: Emission Line sources

- 4082 spectra in PEARS-N
  - 369 emission line objects
- 5539 spectra in PEARS-S
  - 319 emission line objects
- $I_{AB} \sim 36$



Finkelstein 2005, z~4.5 Ly-α

SUMMARY

- Spectra, even low resolution ones, are essential in identifying high z objects.
- ACS Grism mode is efficient and very sensitive to emission lines.
- Identified a small number of very faint sources in the HUDF with Ly-α emission. The number of sources we detect are consistent with narrow band surveys (Pirzkal et al. 2007)
- High redshift galaxies selected on the basis of their strong Lyman-α emission tend to have:
    - Physically small sizes
    - Very low masses
    - Low extinction values
    - Low metallicity
    - Busy forming stars
- Are these future hierarchical merging building blocks?

Further Reading

- Rhoads, J. E., et al 2004, "A Redshift z=5.4 Lyman alpha Emitting Galaxy with Linear Morphology in the GRAPES/UDF Field," The Astrophysical Journal. astro-ph/0408031 [accepted]
- Pirzkal, N., Xu, C., Malhotra, S., Rhoads, J. E., et al 2004, "GRAPES, Grism Spectroscopy of the Hubble Ultra Deep Field: Description and Data Reduction," The Astrophysical Journal Supplements, 154, 501. ADS/abstract, astro-ph/0403458 [accepted]
- Pirzkal, N., Sahu, K. C., Burgasser, A. et al 2005, "Stars in the Hubble Ultra Deep Field", The Astrophysical Journal astro-ph/0412097 [accepted]
- Daddi, E., Renzini, A., Pirzkal, N. et al 2005, "Passively Evolving Early-type Galaxies at 1.4<z<2.5 in the Hubble Ultra Deep Field", The Astrophysical Journal, astro-ph/0503102] [accepted]
- Malhotra, S., Rhoads, J. E., Pirzkal, N. et al 2005, "An Overdensity of galaxies at z=5.9+-0.2 in the Ultra Deep Field confirmed using the ACS grism", The Astrophysical Journal, astro-ph/0501478 [accepted]
- Pasquali, A., Ferreras, N., Panagia, N., et al 2005, "The Structure and Star Formation History of Early-Type Galaxies in the UDF/GRAPES Survey", The Astrophysical Journal, astro-ph/0504264 [accepted]
- Pirzkal, N., Xu, C., Ferreras, I., et al 2005, "Morphology and evolution of emission line galaxies in the Hubble Ultra Deep Field", The Astrophysical Journal, astro-ph/0509551 [accepted]
- Xu, C., Pirzkal, N., Malhotra, S., et al 2007, "Redshifts of Emission Line Objects in the Hubble Ultra Deep Field", The Astronomical Journal, astro-ph/0701875 [accepted]
- Ryan, R. E. Jr., Hathi, N. P., Cohen, S. H., et al 2007, "The Galaxy Luminosity Function at z~1 in the HUDF: Probing the Dwarf Population", The Astrophysical Journal, astro-ph/0703743 [accepted]
- Pirzkal, N., Malhotra, S., et al 2007, "Optical to mid-IR observations of Lyman-alpha galaxies at redshift 5 in the HUDF: a young and low mass population", The Astrophysical Journal, astro-ph/0612513 [accepted]