HST/NICMOS & Spitzer/IRAC Observations of 5.7<z<7 Galaxies in the Subaru Deep Field

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See also the poster by Finkelstein et al.

Collaborators

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Subaru SDF

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Lensing cluster survey

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IRAC team

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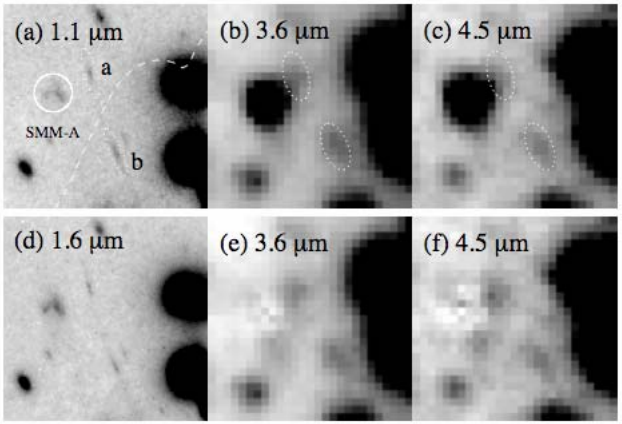
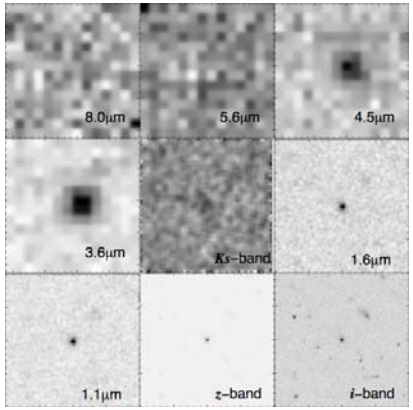
Simulations

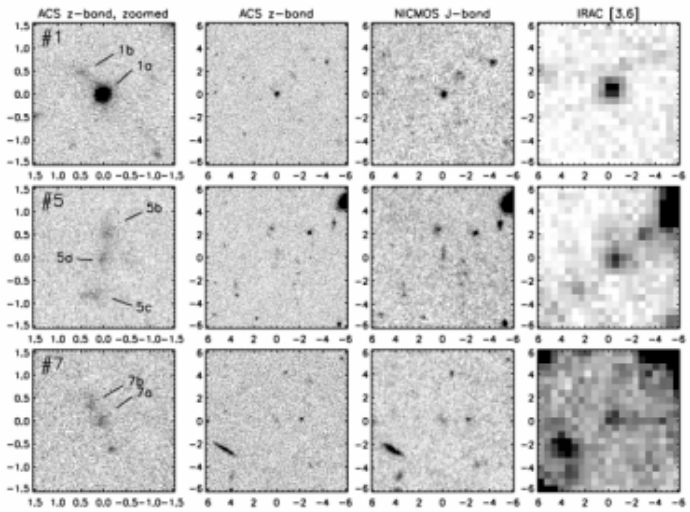
Spitzer/IRAC Detections of $z \geq 6$ Galaxies

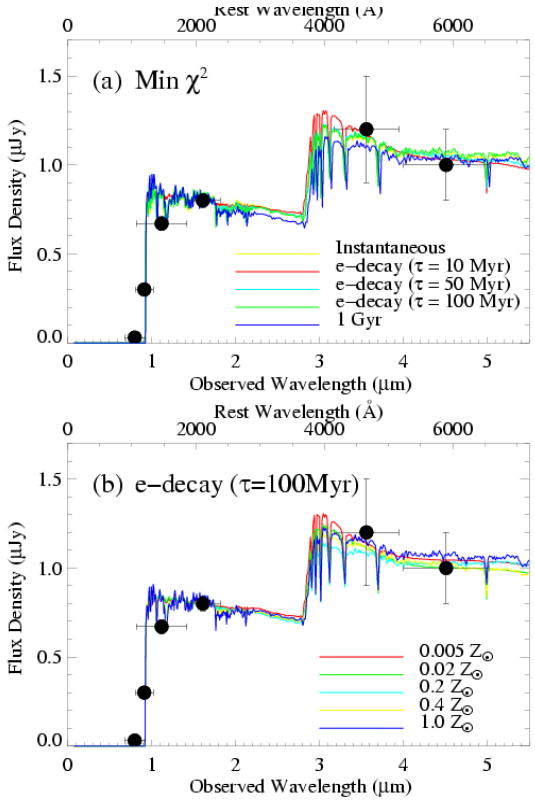
- IRAC on Spitzer (D=85cm telescope!) has enabled us to study the rest-frame optical SEDs of z>6 galaxies.
  - 3.6/4.5um bands are longward of the rest-frame Balmer/4000 A break at z<8
- Some z>6 galaxies seem fairly mature and massive (age ~ 200-300 Myr, $\sim 10^{9}$-$10^{10} M_{\odot}$)
- However, the majority seems young and less massive (age < 50-100 Myr, $\sim 10^{8} \sim 10^{9} M_{\odot}$)

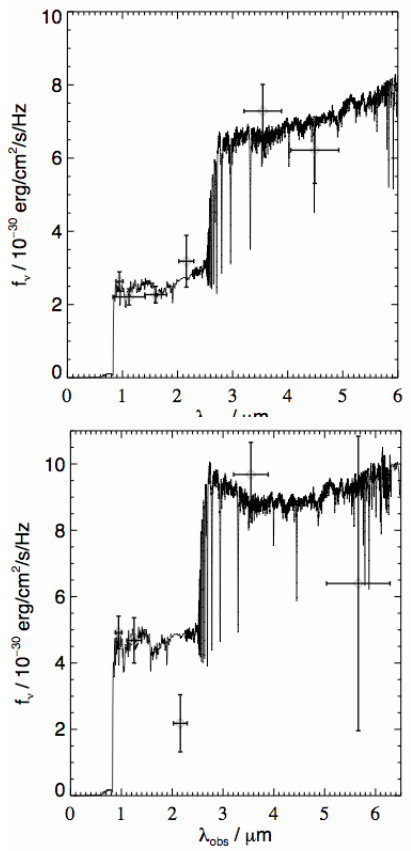
Mature galaxies at z>6!

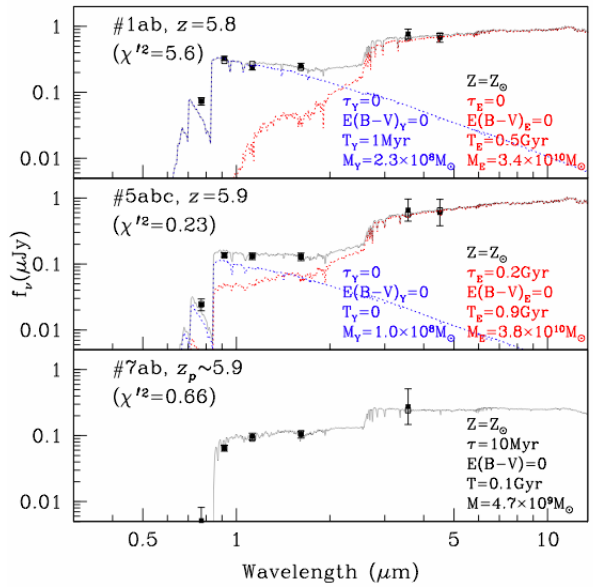












Egami et al. 2005

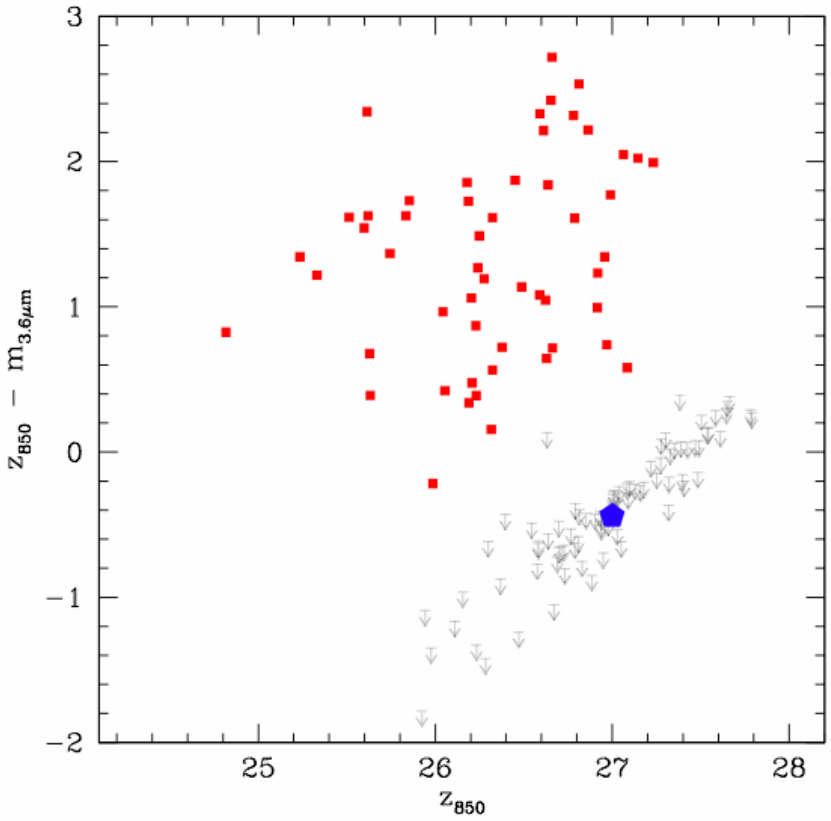
Eyles et al. 2005

Yan et al. 2005

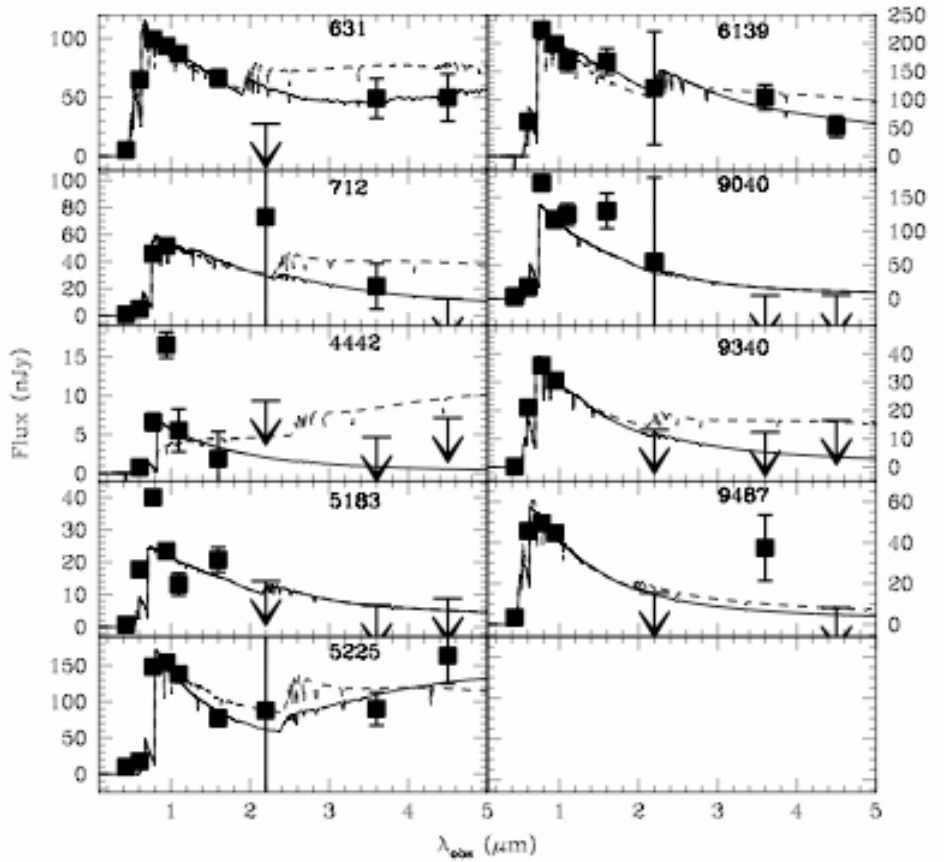
BUT, there are also many young lower-mass galaxies

z~6, i dropouts
< 40 Myr, ~$10^9 M_\odot$

z=4.0-5.7, LAEs
2-3 Myr, 10^6-10^8 $M_\odot$



Yan et al. 2006

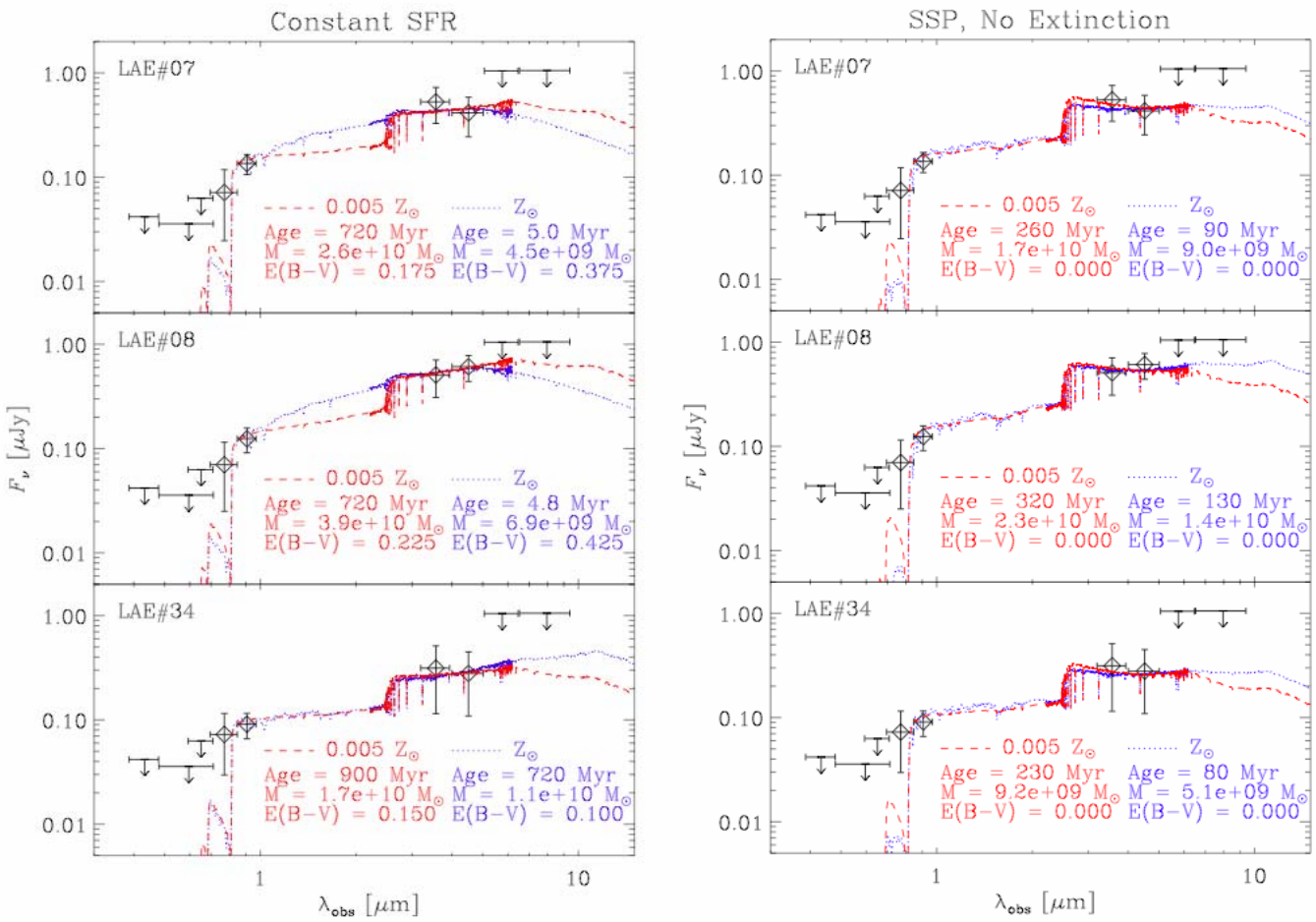


Pirzkal et al. 2007

Limitations of the Past Studies

- Targets were selected in deep but small-field surveys (e.g., UDF, GOODS)
  - Sources are faint (especially for IRAC!)
    ➔ Uncertainty with photometry, phot-z, SED modeling, etc.
  - Spectroscopic redshifts not available in most cases
  - Deep near-IR coverage limited

Importance of Near-IR Data



Lai et al. (2007)

Near-IR data are required to break SED model degeneracy (e.g., young dusty population vs old dust-free population)

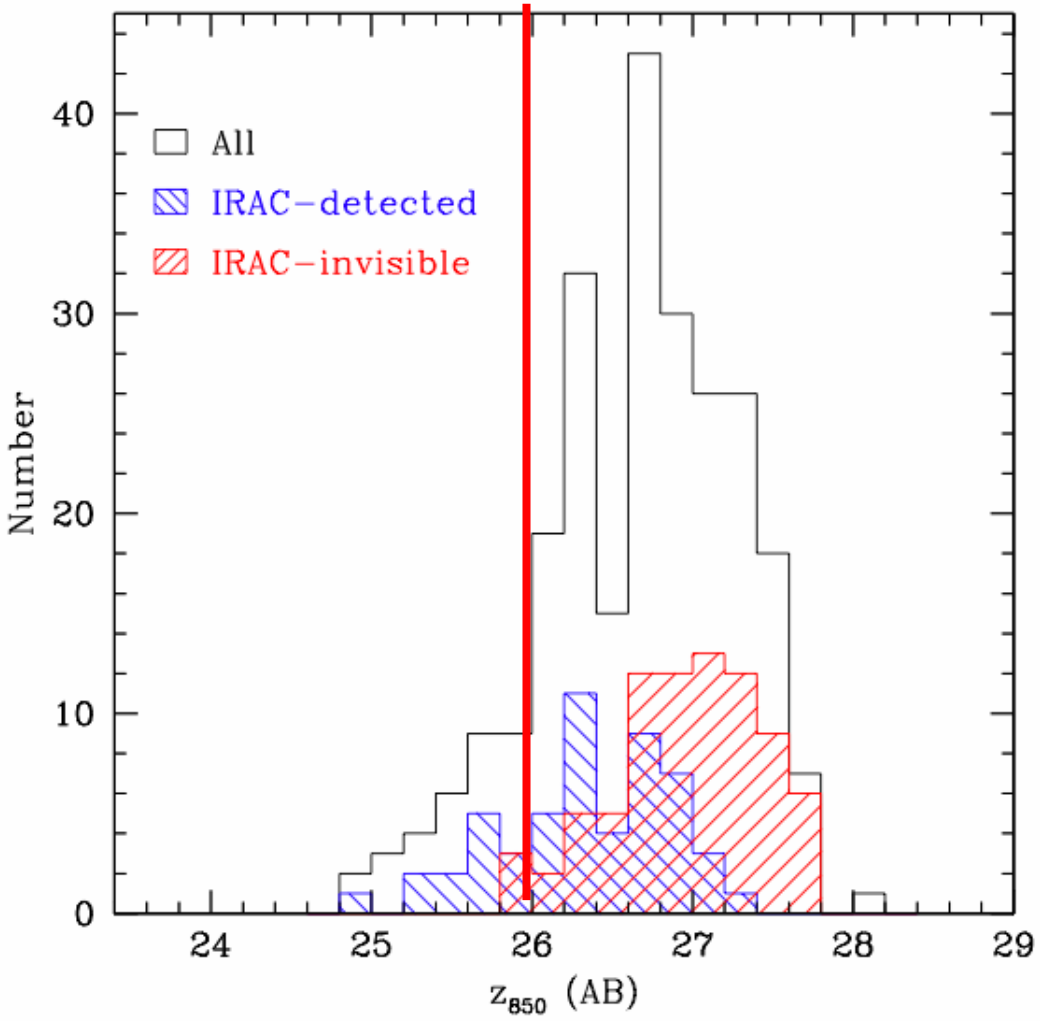
Our Strategy

- Target bright (z< 26 AB mag = 0.14 uJy) galaxies with spectroscopic redshifts at 5.7<z<7 -> Subaru Deep Field (SDF)
- Use HST/NICMOS (1.1/1.6 um) and Spitzer/IRAC (3.6/4.5 um) to obtain SEDs.
- Go after source by source instead of mapping a sky area uniformly.
- Ly-alpha properties and continuum properties can be compared.
- Drawback: the sample is biased toward the most luminous galaxies

Subaru Deep Field (SDF)

- Deep Suprime-Cam broad/narrow-band imaging over ~30'x30' (Kashikawa et al. 2004):
  - z~7 LAE survey (Iye et al. 2006)
  - z~6.5 LAE survey (Kodaira et al. 2003; Taniguchi et al. 2005; Kashikawa et al.2006)
  - z~6 LBG survey (Nagao et al. 2004, 2005, 2007; Ota 2008)
  - z~5.7 LAE survey (Shimasaku et al. 2006)

Our target selection for SDF

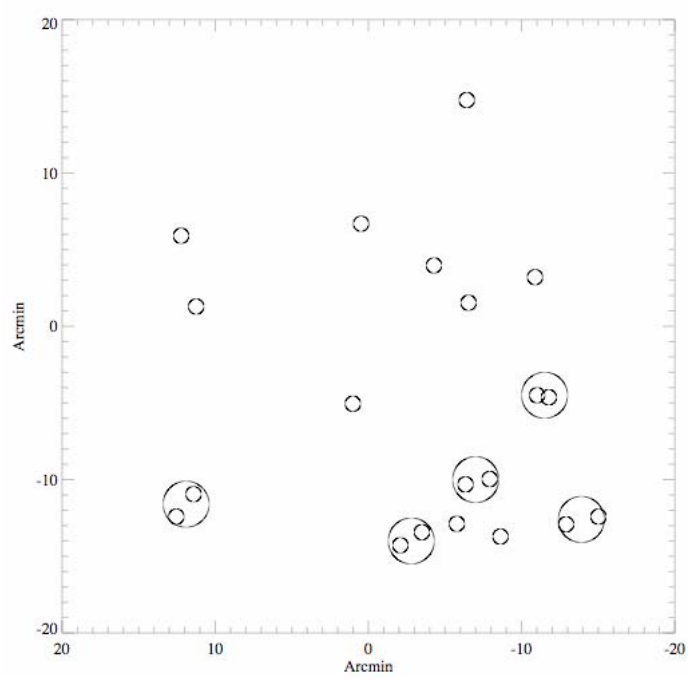


Yan et al. (2006)

GOODS sample

HST-Spitzer Coordinated Program

- 20 targets with spec-z
  - 20 NICMOS pointings
  - 15 IRAC pointings
- NICMOS (72 orbits)
  - F110W & F160W ; NIC3
  - 1-2 orbits/band
- IRAC (102 hrs)
  - 3.6 um & 4.5 um
  - 3 hrs/band
  - 5.8 & 8.0um data obtained simultaneously

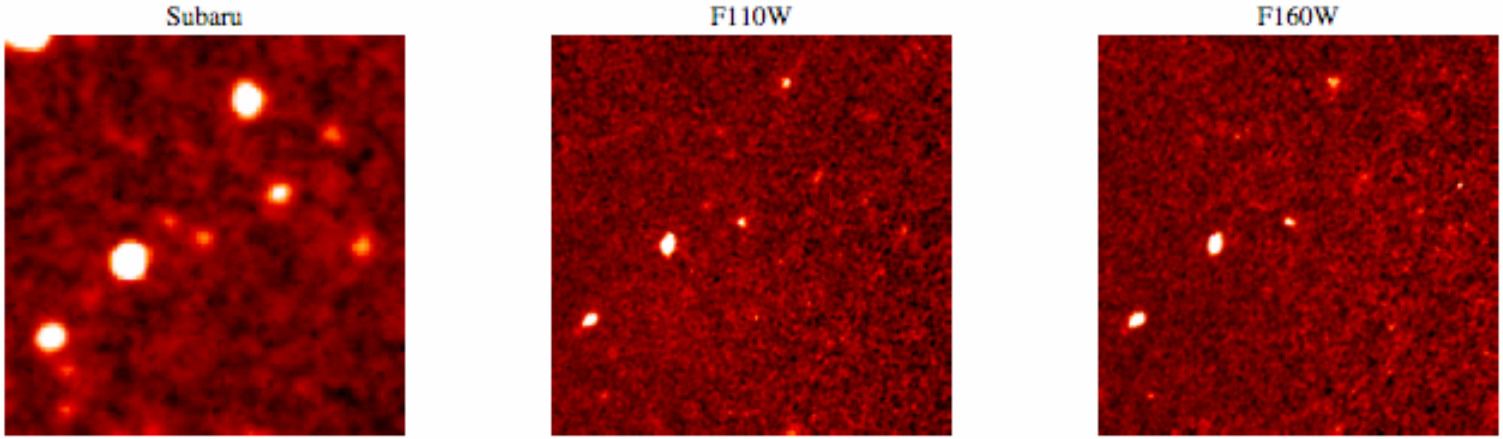


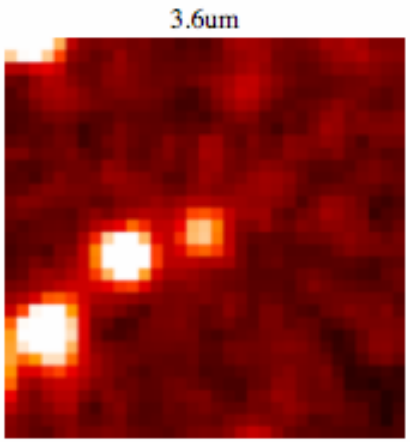
Target list

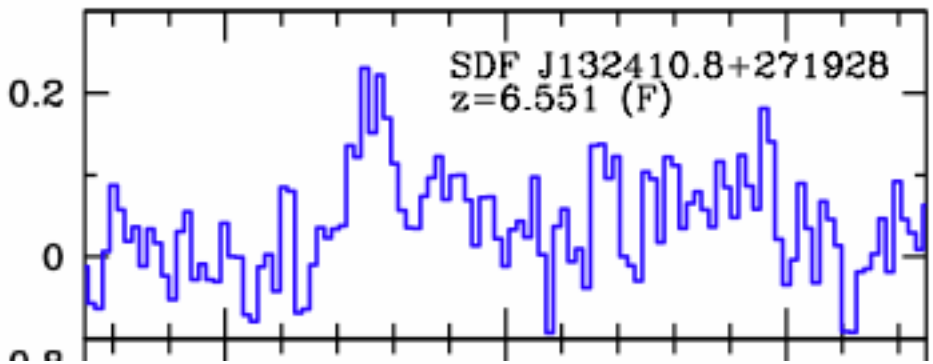
Table 1: Spectroscopically confirmed bright ($z'_{AB} < 26.0$ mag) $z = 5.7 - 7$ galaxies in the SDF

Target	z_{spec}	Type	z'_{AB}	Ref	Target	z_{spec}	Type	z'_{AB}	Ref
SDFJ132359.8+272456	6.96	LAE	26.4[a]	8	SDFJ132400.3+273238	6.06	LBG	25.88	5
SDFJ132522.3+273520	6.597	LAE	25.57[a]	1	SDFJ132442.5+272423	6.04	LBG	25.74	6
SDFJ132357.1+272448	6.589	LAE	25.17[a]	1,2	SDFJ132426.5+271600	6.03	LBG	25.36	6
SDFJ132518.8+273043	6.578	LAE	25.81[a]	1	SDFJ132431.5+271509	6.03	LBG	25.89	5
SDFJ132408.3+271543	6.554	LAE	24.94[a]	1,3	SDFJ132519.4+271829	6.00	LBG	25.42	9
SDFJ132410.8+271928	6.551	LAE	25.13[a]	1,2	SDFJ132418.4+271633	5.914	LAE	25.75	5
SDFJ132415.7+273058	6.541	LAE	24.73[a]	1,3	SDFJ132423.7+273324	5.710	LAE	24.73	7
SDFJ132353.1+271631	6.540	LAE	25.57[a]	1	SDFJ132523.4+271701	5.705	LAE	25.34	7
SDFJ132440.6+273607	6.33	LBG	25.66	4	SDFJ132416.1+274411	5.698	LAE	24.84	7
SDFJ132345.6+271701	6.11	LBG	25.24	9	SDFJ132416.4+271907	5.665	LAE	25.37	7

LAE at z=6.55

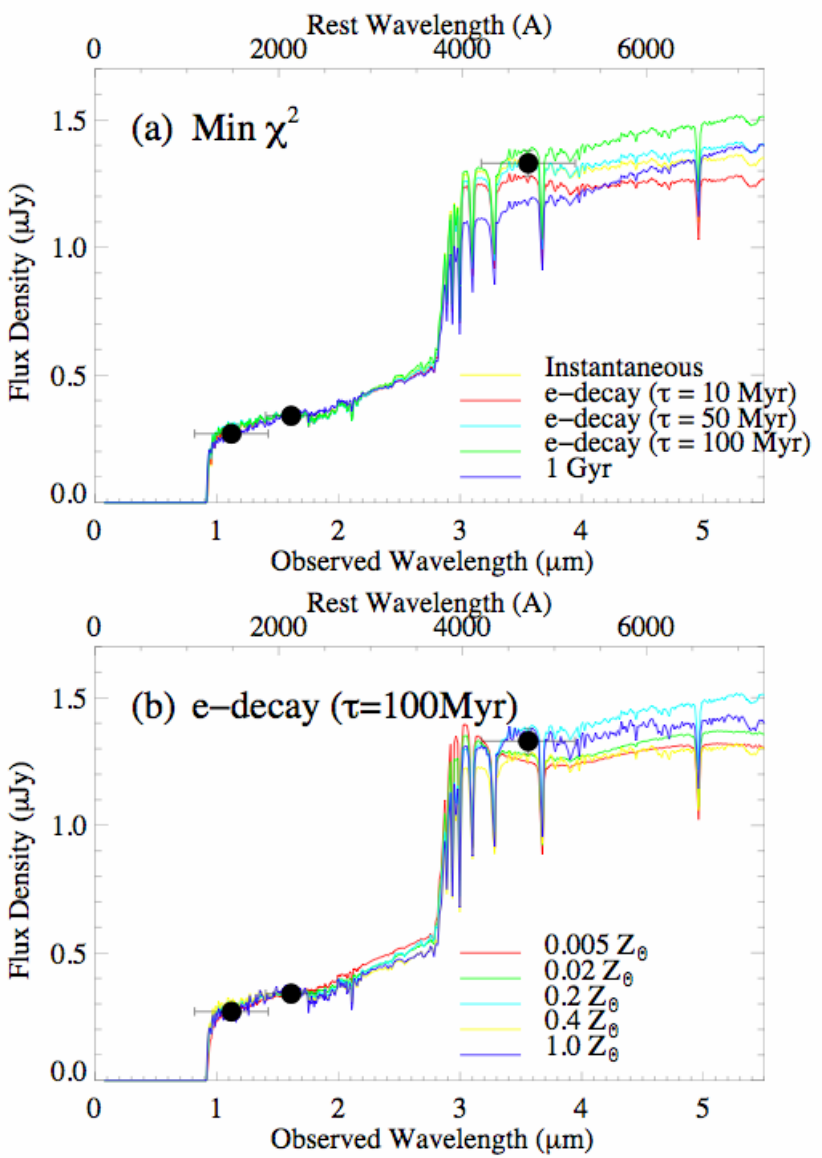






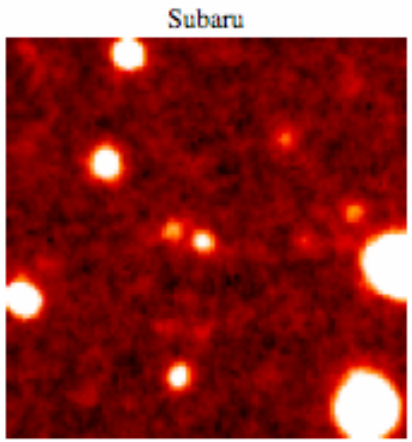
Kashikawa et al. (2006)

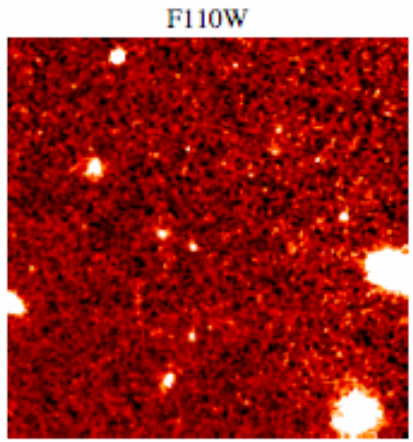
LAE at z=6.55 - SED

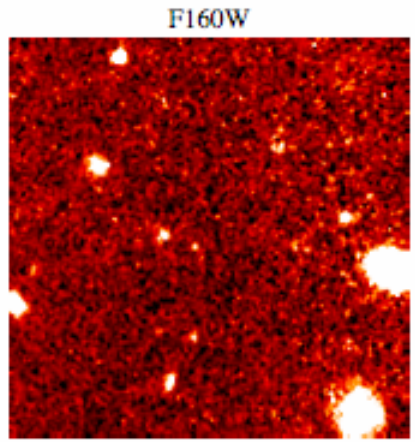


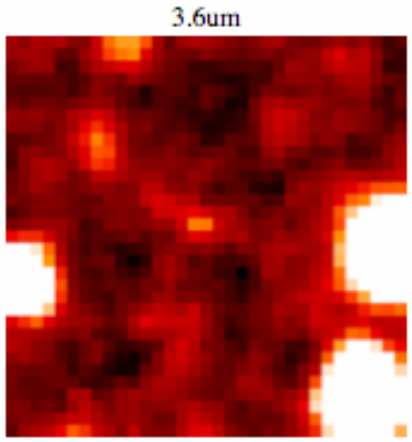
- Bruzual-Charlot 2003 models
- Salpeter IMF (0.1-100 $M_\odot$)
- Age 300-400 Myr (> 200 Myr)
- z_form ~ 10
- Mass 3-4x10^{10} $M_\odot$
- Mature massive galaxy with little extinction

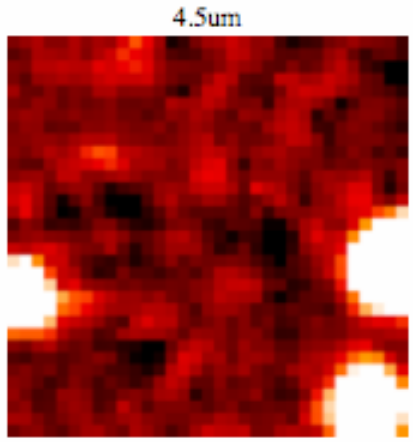
i’-dropout at z=6.11

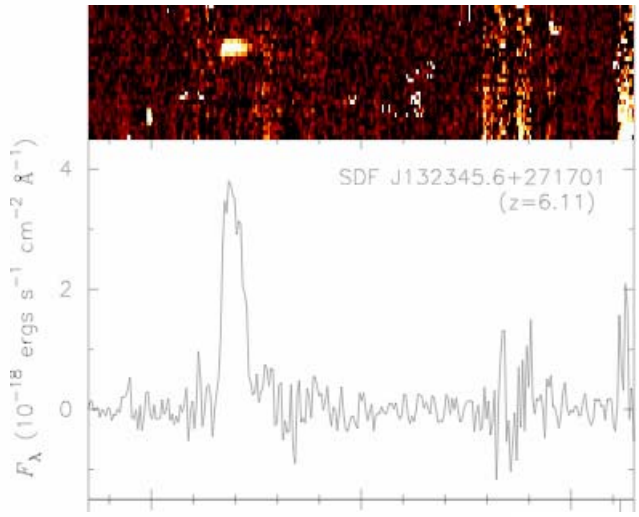




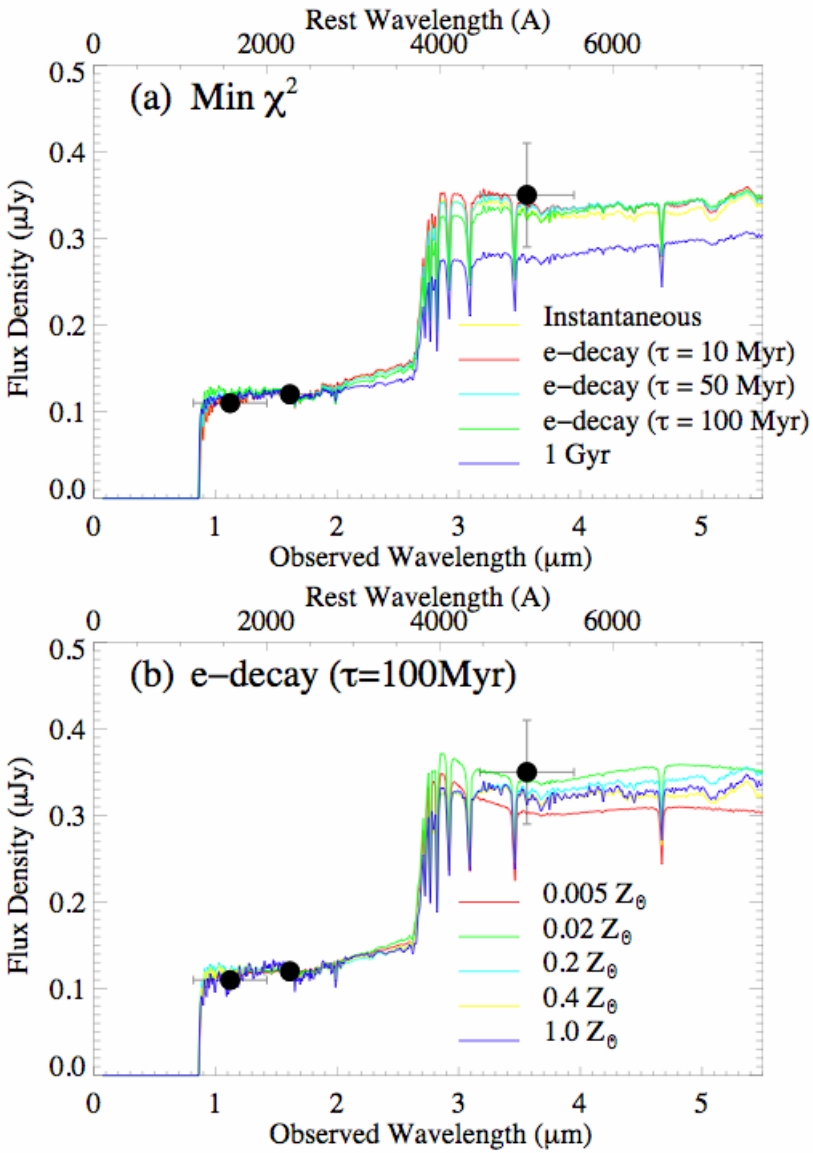






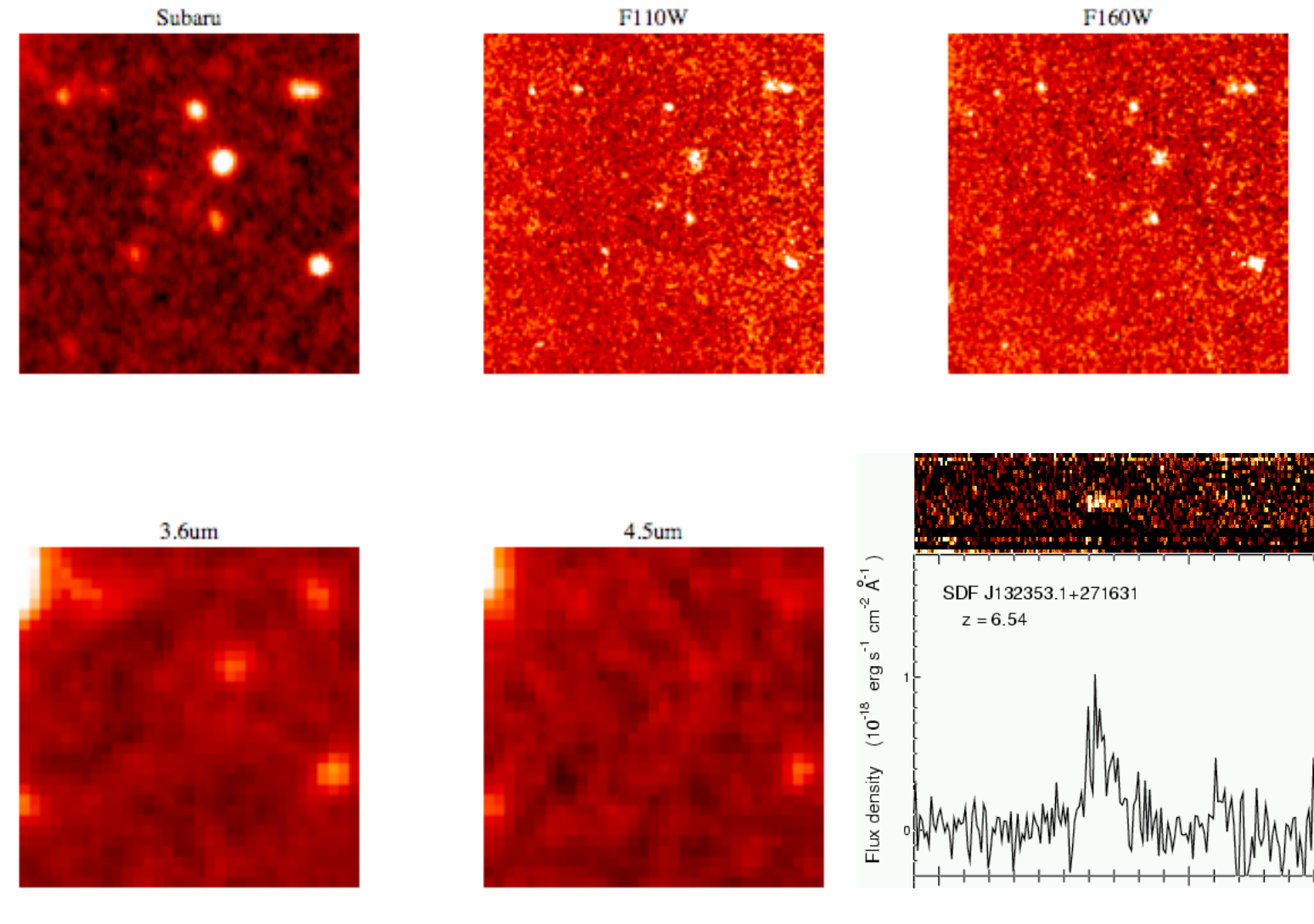


i'-dropout at z=6.11 - SED



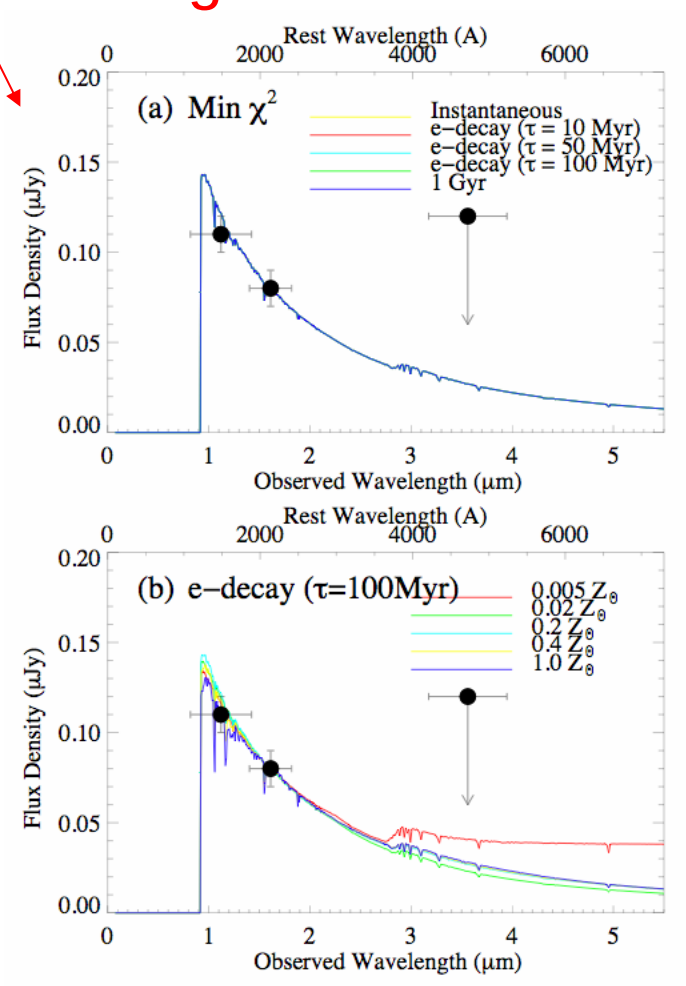
- Age 200-300 Myr (> 100 Myr)
- Mass ~ 7×10^9 $M_\odot$
- Mature galaxy with little extiction (less massive than the previous one)

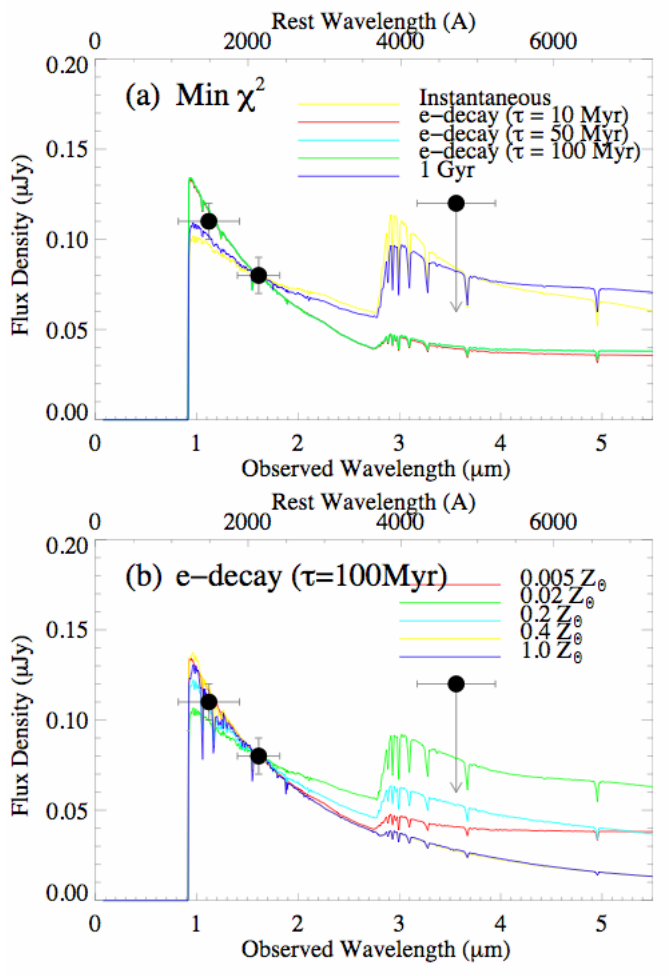
LAE at z=6.54


Subaru
F110W
F160W
3.6um
4.5um
SDF J132353.1+271631
z = 6.54
Flux density (10^-18 erg s^-1 cm^-2 Å^-1)
1
0

LAE at z=6.54 -SED

Very small age not likely, SFR too large





Age ~ 1 Myr

Age ~ 10-100 Myr

In almost all cases, sub-solar metallicity seems required to reproduce the UV slope.

Status & Next steps

- ~1/3 done so far
  - 8 sources observed with NICMOS
  - 7 sources observed with IRAC
  - BUT, only 4 sources common….
- Remaining HST imaging (12 sources) will be done with WFC3
- One more Spitzer visibility window during the cold mission -> if the program cannot be completed, we will try the warm mission.
- Photometric samples will also be studied.

Summary

- We are currently conducting a HST/NICMOS - Spitzer/IRAC coordinated program, trying to obtain accurate SEDs for 20 galaxies at $5.7<z<7$ with spectroscopic redshifts.
- In the small sample at hand (only a few), we see (1) mature old galaxies, and (2) young galaxies, as the previous studies showed. The latter have much steeper UV slope.
- So far, we have not seen any indication of significant dust extinction.