Evolution of Lyα Galaxies Over 9 Gyr of Cosmic Time

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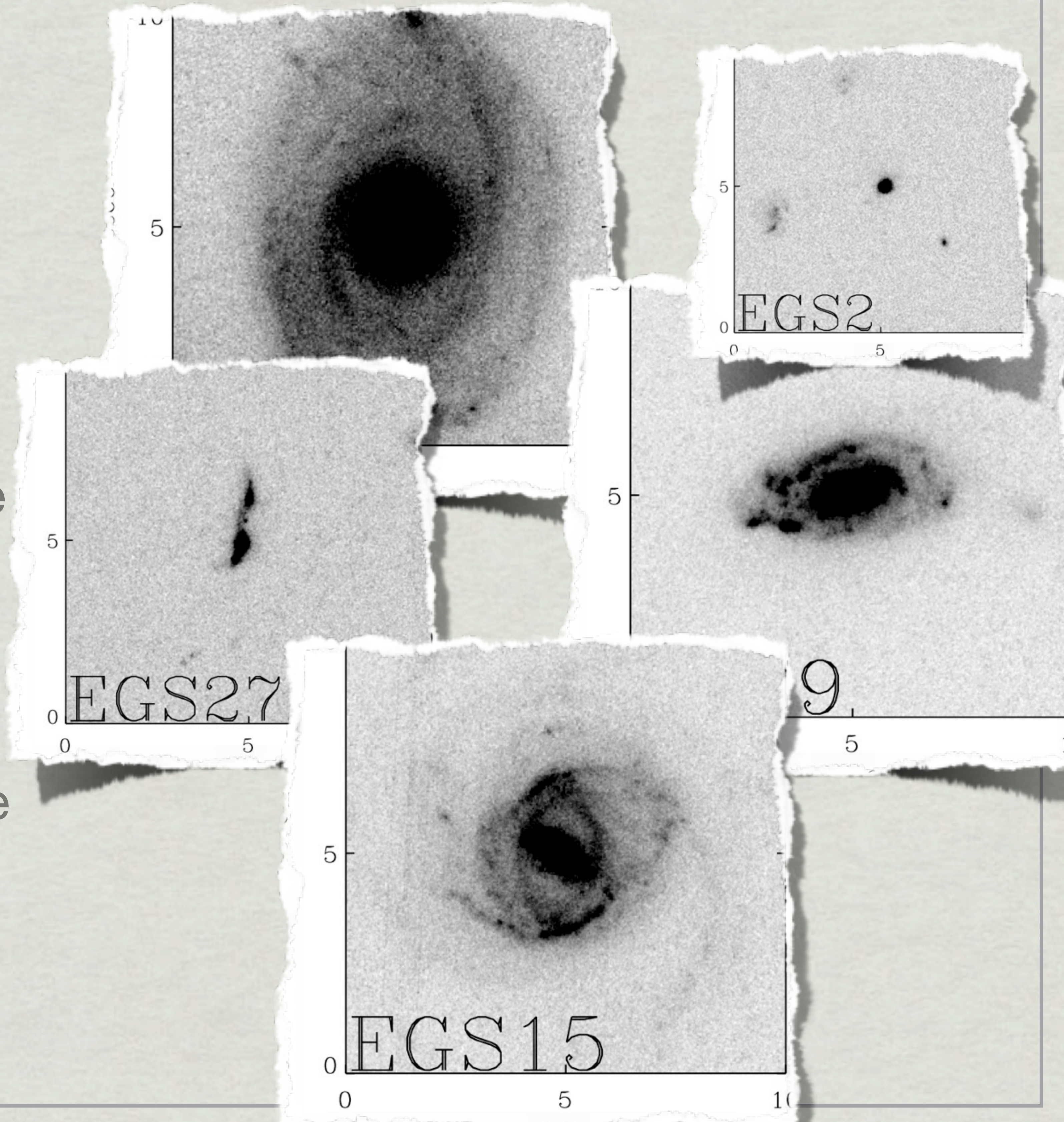
What we think we know at high-z

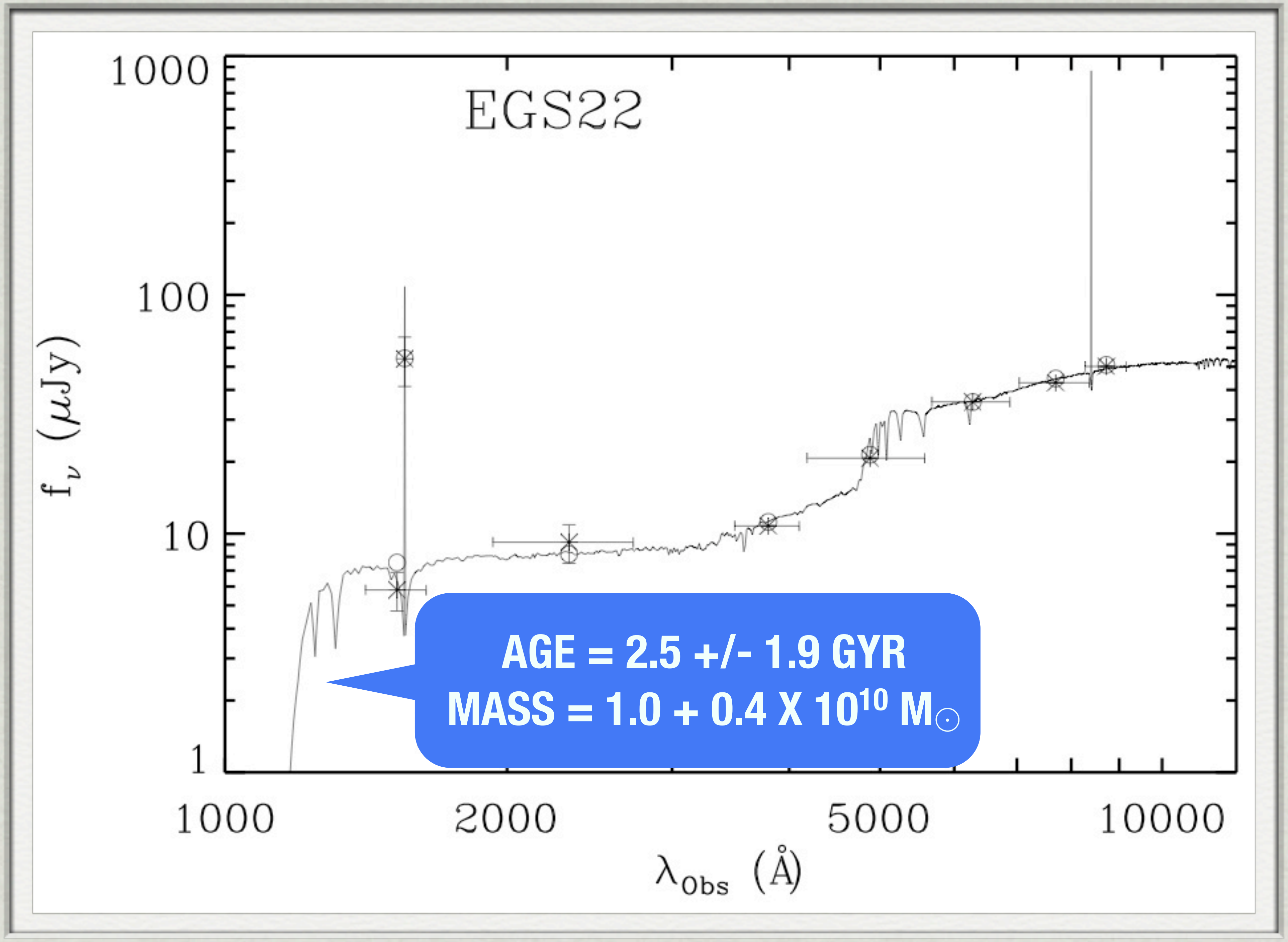
- Stellar populations of LAEs have been studied over $3 \leq z \leq 6$.
    - e.g., Chary et al. 2005; Gawiser et al. 2006; Pirzkal et al. 2007; Nilsson et al. 2007; Lai et al. 2007,2008; Pentericci et al. 2009; Finkelstein et al. 2007, 2008, 2009a.
- A wide range of physical properties are found, they may depend on the depth of the study.
    - Pirzkal et al. studied LAEs from the HUDF, and due to the small volume and faint luminosities probed, they found very young ages and low masses - a few Myr and 10^{6-8} $M_{\odot}$.
    - Lai et al. (2007, 2008) and Finkelstein et al. (2008, 2009a) studied IRAC detected LAEs, and found these to be more massive, up to ~ 5 x 10^{10} $M_{\odot}$.
        - Recent results (see McLinden et al. poster) confirm this variety at z ~ 3.1, finding 7/8 spec. conf. LAEs are young, and that one old one may have a mass of ~ 10^{11} $M_{\odot}$.
- Regardless of selection, LAEs older than a few hundred Myr are rare, thus as a population, they still appear to be predominately young, and their properties don't change with redshift.
- What about closer to home? Are there LAEs? Are they different?

GALEX Discovered LAEs

- Devarveng et al. (2008) discovered ~ 100 LAEs with *GALEX* spectroscopy.
- We found optical counterparts to 30 of these: 3 in the ECDF-S with MUSYC, and 27 in the EGS with the CFHTLS.
- Using the UV+optical fluxes, we fit stellar population models to these objects
- **Finkelstein et al. 2009c, ApJ, 700, 276**

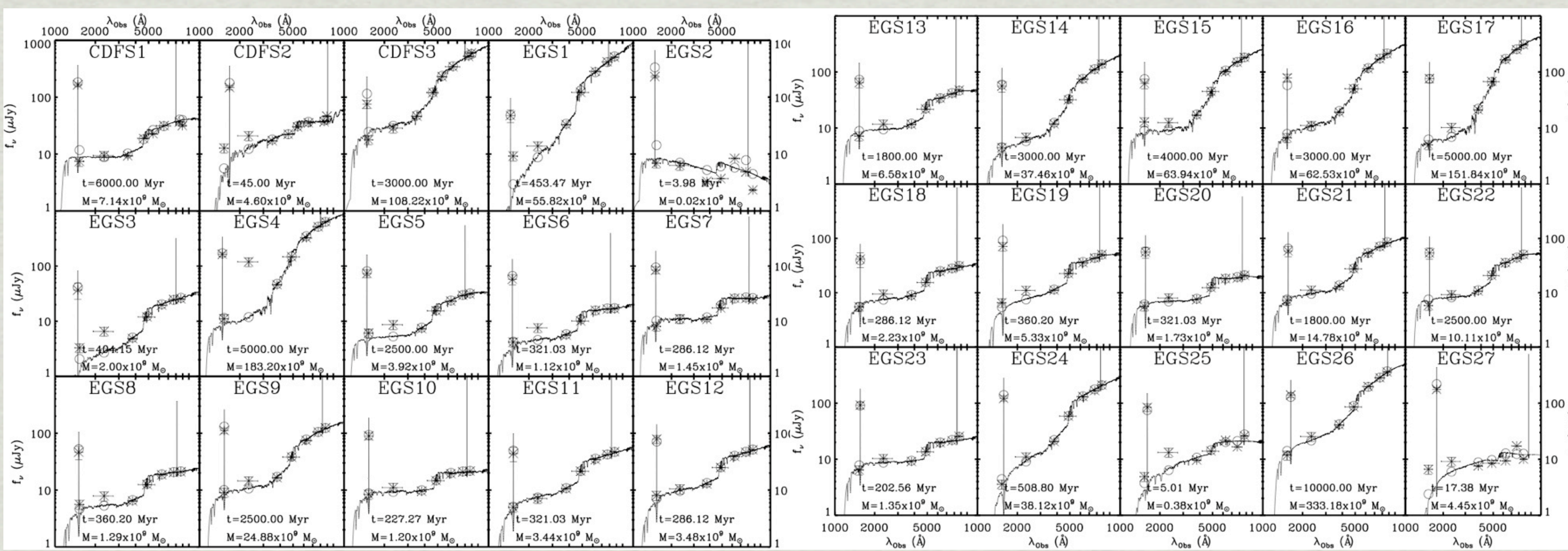


Model Fitting Results



Model Fitting Results

- From the 26/30 objects which we could fit well:
  - 200 Myr < Age < 10 Gyr (median ~ 1.8 Gyr)
  - 10^9 $M_\odot$ < Mass < 3 x 10^{11} $M_\odot$ (median ~ 7 x 10^9 $M_\odot$)



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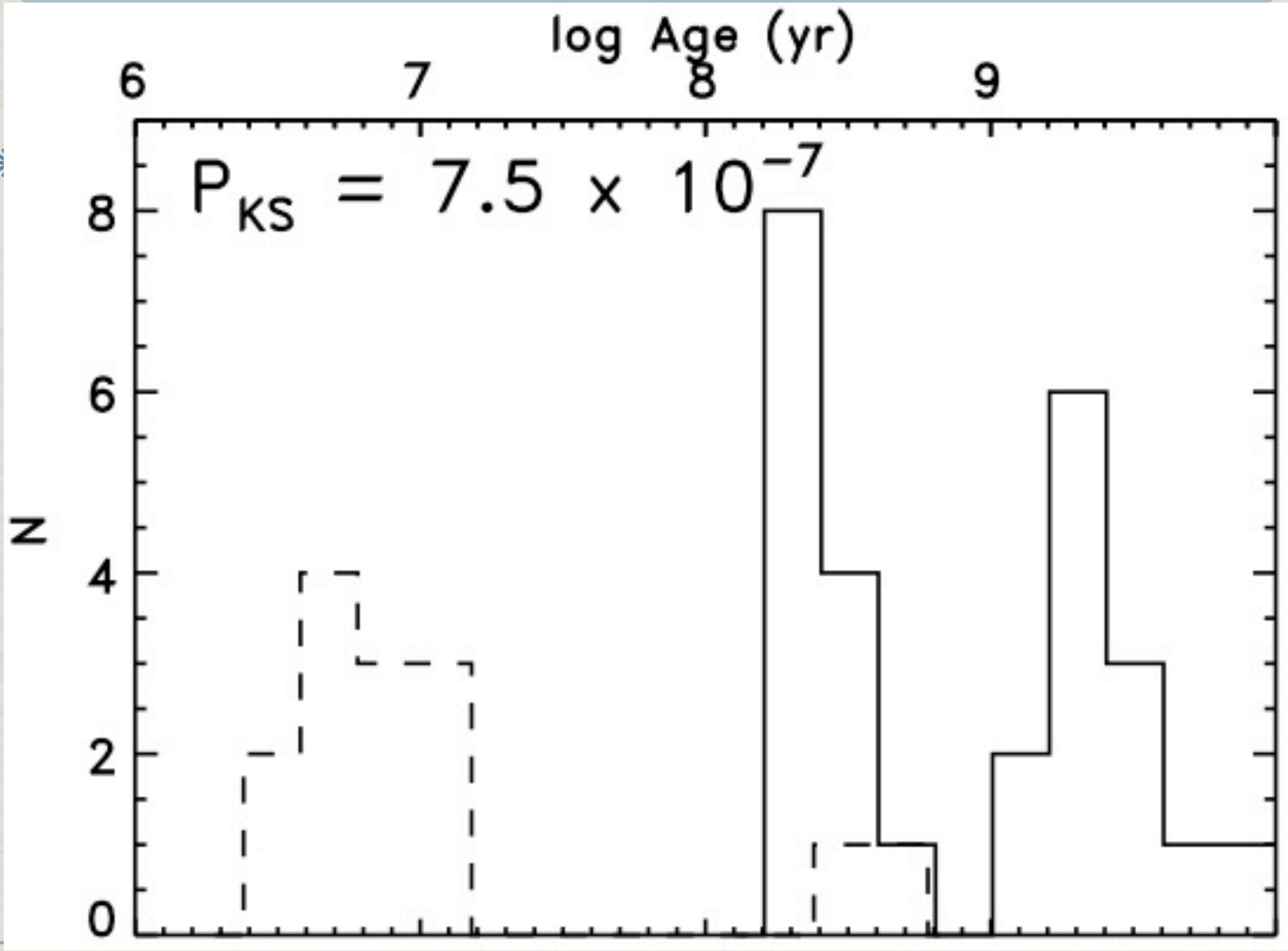
z	*Age*	*Mass*
3	*A few Myr - 1 Gyr*	10^8 - 10^{10} $M_\odot$
4.5	*3 - 500 Myr*	~ 10^8 - 5×10^{10} $M_\odot$
~ 5 - 6	*A few - 700 Myr*	10^7 - 10^{10}

KS TEST BETWEEN Z ~ 0.3 (SOLID) AND Z ~ 4.5 (DASHED) SAMPLES

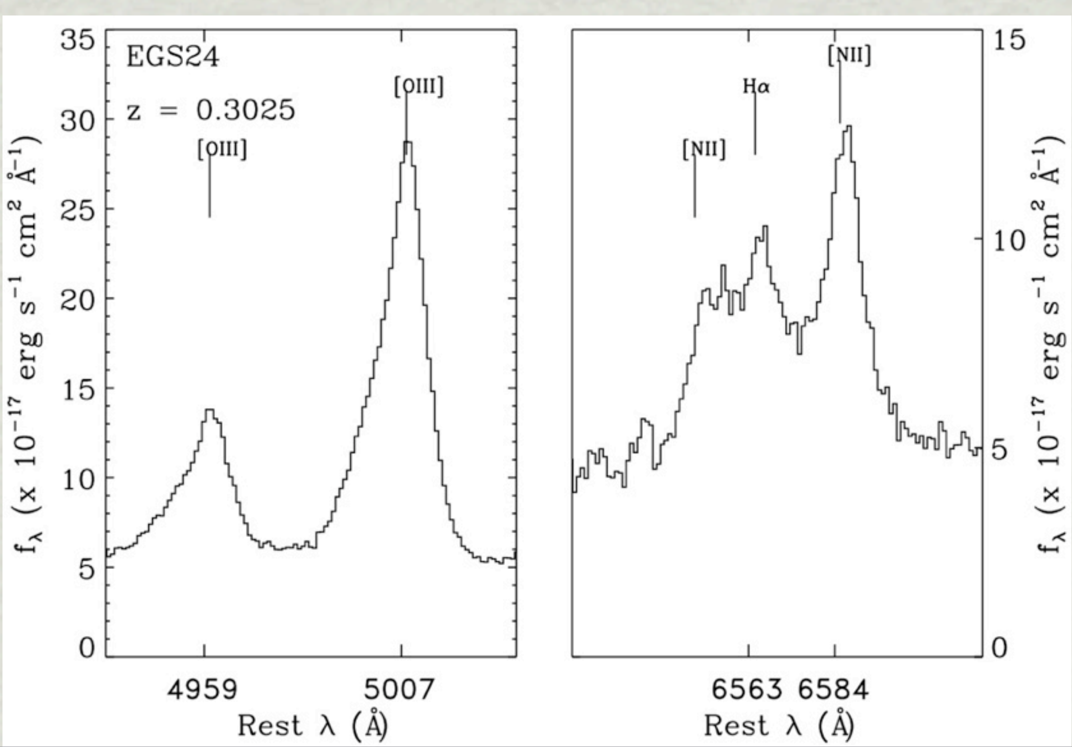


AGN Contamination?

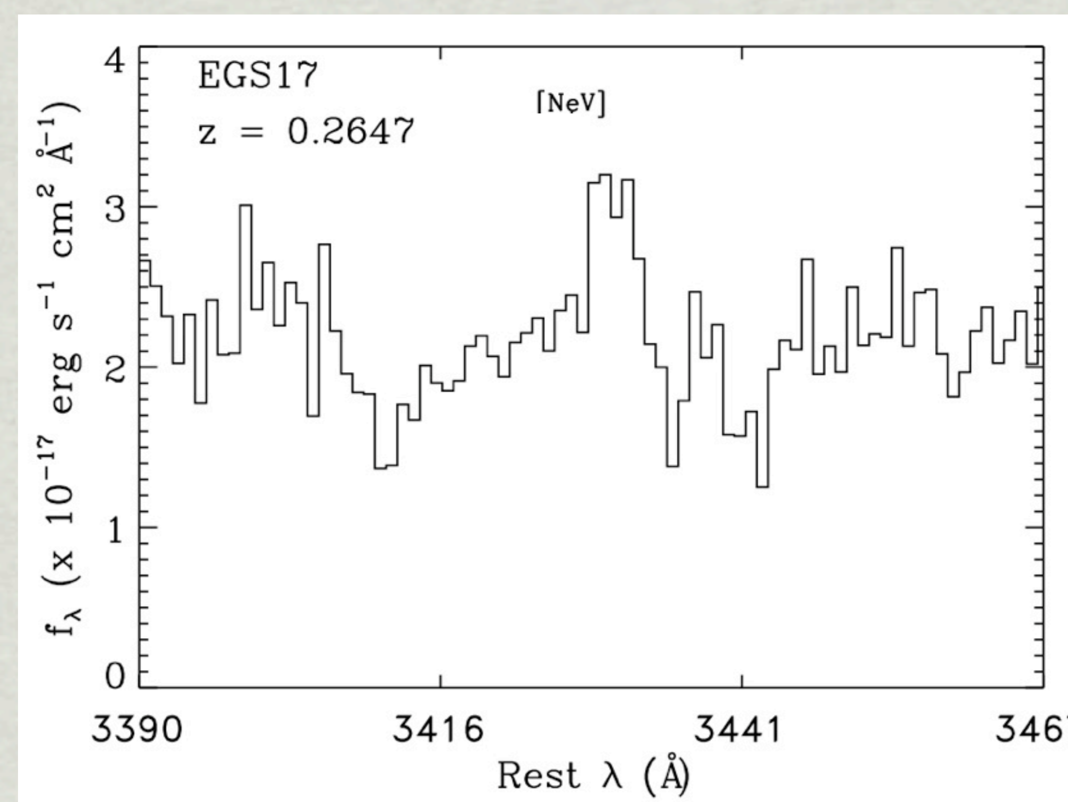
- A number of the SEDs appeared to be very red.
  - Could be very dusty, or could be from an AGN-like power-law spectrum.
- We thus obtained optical spectroscopy of 23/27 EGS LAEs with Hectospec on the 6.5m MMT
  - Finkelstein et al. 2009e, under review at ApJL, astro-ph/0906:4554
- We fit Gaussian line profiles to detected lines in all objects, with line errors estimated via 10^3 Monte Carlo simulations.
  - **We then performed multiple tests for the presence of AGN.**

Line Widths and High-Ionization Emission

- Emission lines from the broad-line region of AGNs typically show $\Delta v \geq 1000$ km s^{-1}.
- Only one object had $\Delta v > 1000$, with $\Delta v = 1064$ km s^{-1}.
- The remaining objects had $\Delta v < 300$ km s^{-1}.



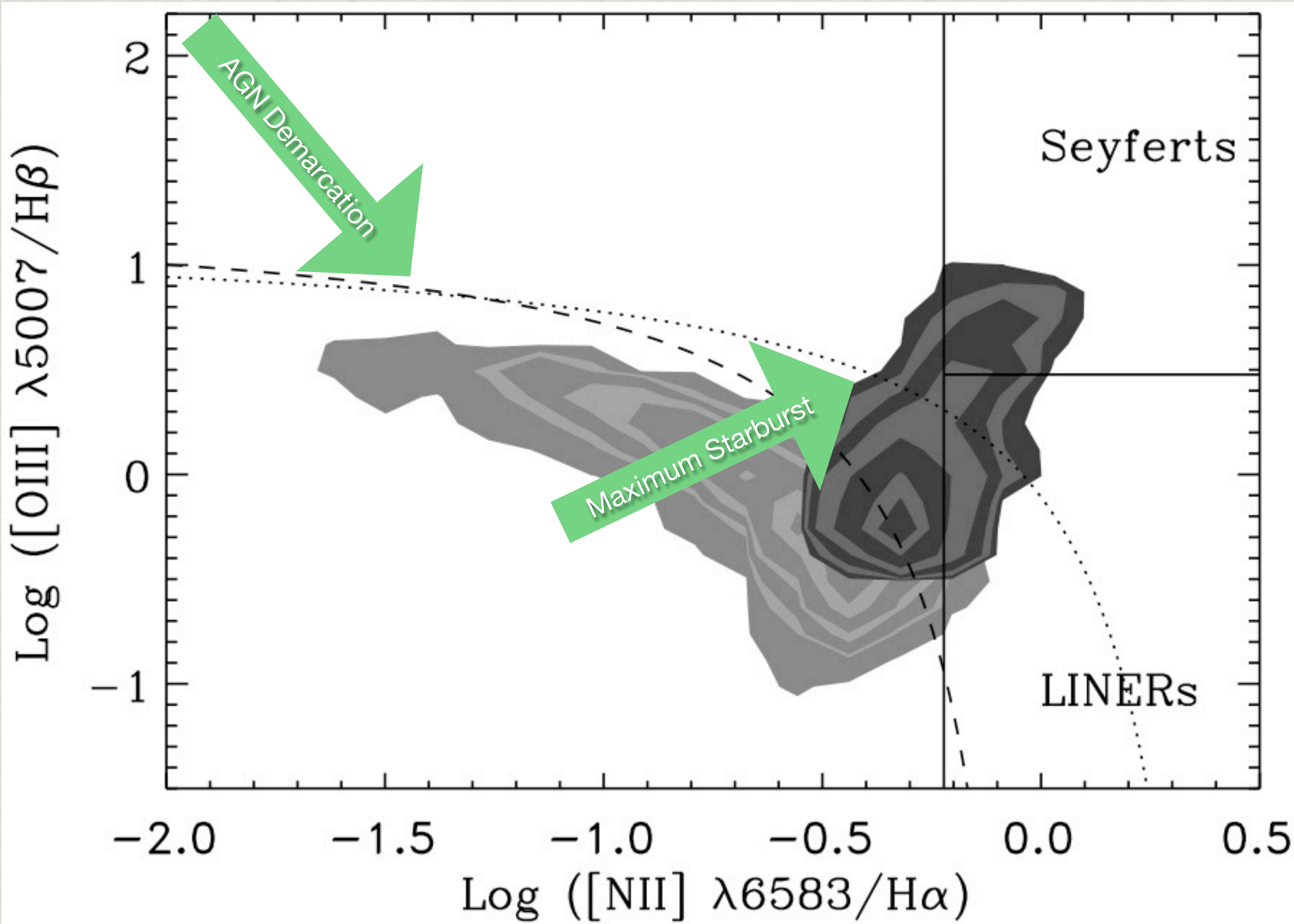
- [NeV] takes 126 eV to ionize ➙ strong AGN indicator.
- We detect [NeV] in four (two) objects at > 3 (2) σ.
- HeII 4686 also typically denotes AGN activity, and we observe this line in one (one) object at > 3 (2) σ in one object.



Line Ratios

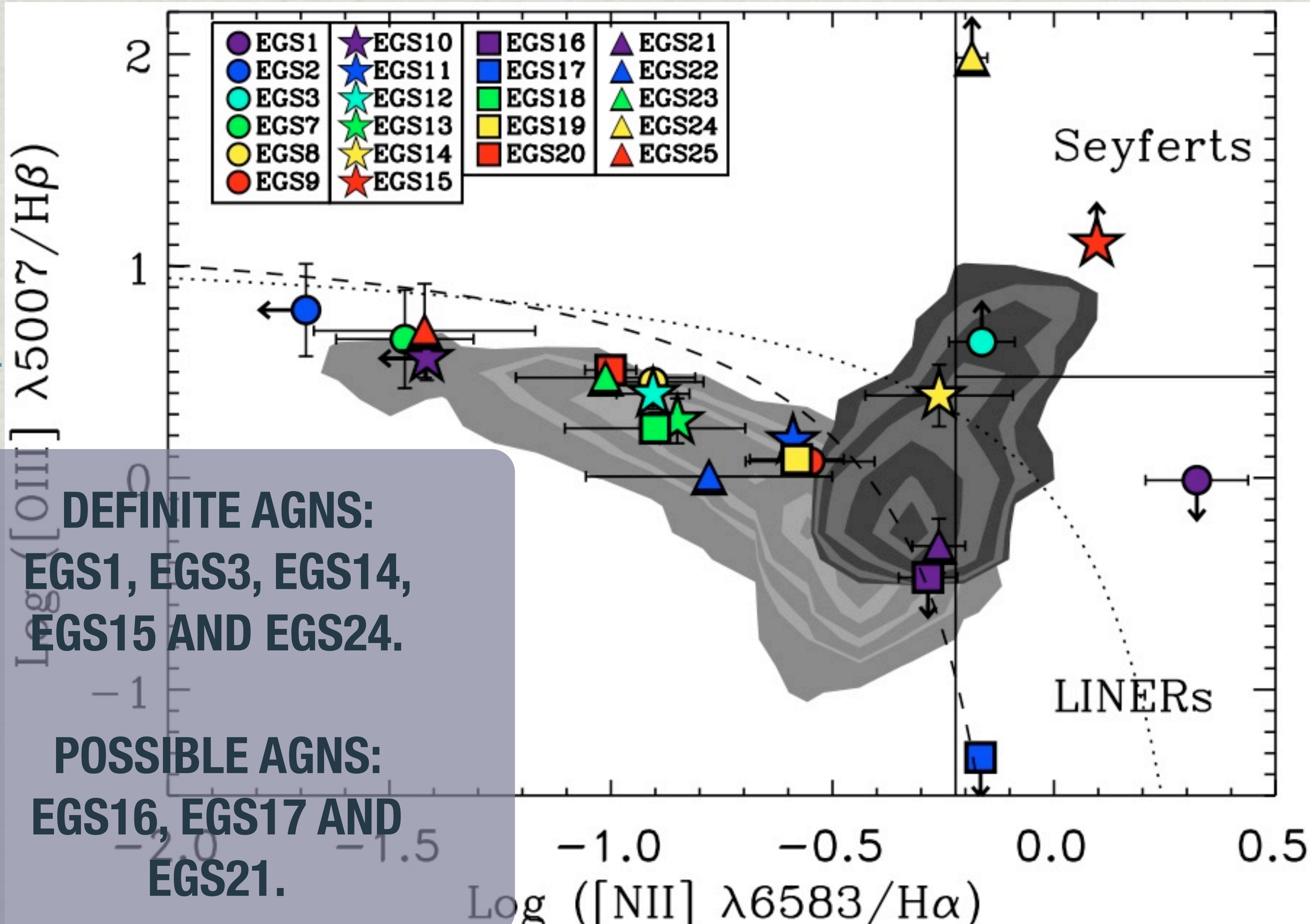
- One of the most commonly used methods to classify AGN relies on the ratios of [NII] 6484/Hα vs. [OIII]/Hβ (Baldwin, Phillips and Terlevich 1981; BPT).

Line Ratios

* 

AGN Demarcation
Maximum Starburst
Seyferts
LINERs
2
1
0
−1
−2.0
−1.5
−1.0
−0.5
0.0
0.5
Log ([OIII] λ5007/Hβ)
Log ([NII] λ6583/Hα)

Line Ratios



- **DEFINITE AGNS: EGS1, EGS3, EGS14, EGS15 AND EGS24.**

  POSSIBLE AGNS: EGS16, EGS17 AND EGS21.

X-rays and Infrared

- Only one object was detected in the AEGIS-X catalog (down to 1.5 x 10^{40} erg s^{-1}). Although its X-ray luminosity alone didn't qualify it as an AGN, combining it with the X-ray hardness ratio satisfies the AGN classification scheme of Szokoly et al. (2004).

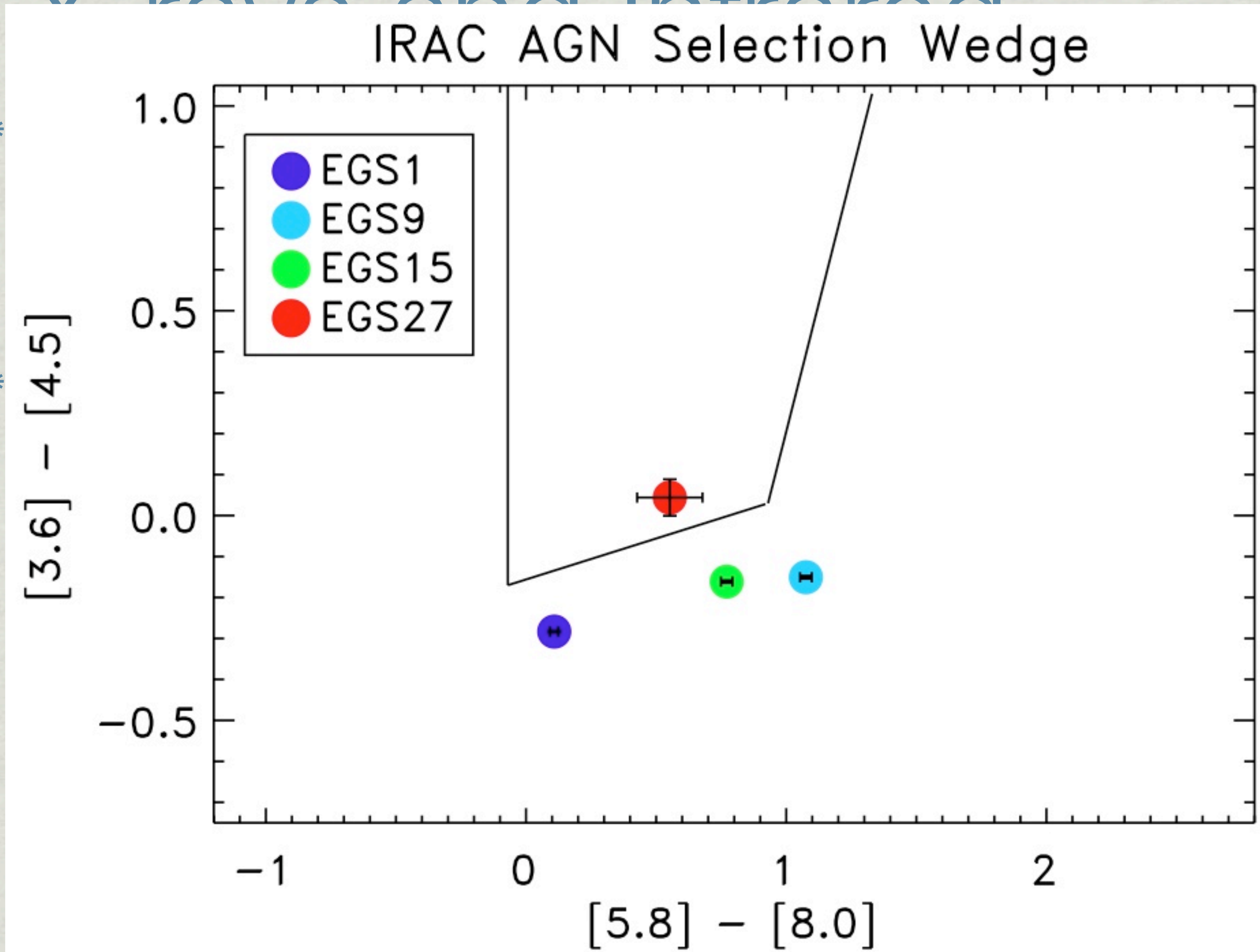
- The rest of the sample, which is not detected in the X-rays, could harbor an obscured AGN.

  - Stern et al. (2005) defined an IRAC color-color region which preferentially selects AGN in the redshift range of our sample, due to hot dust heated by an AGN.

    - Only 4/23 objects had IRAC coverage, and only one EGS27 satisfied these criteria.

  - 9/13 LAEs with MIPS coverage were detected at $> 3\ \sigma$, which could imply emission from slightly cooler dust, although star formation at these redshifts could result in similar emission.

X-rays and Infrared

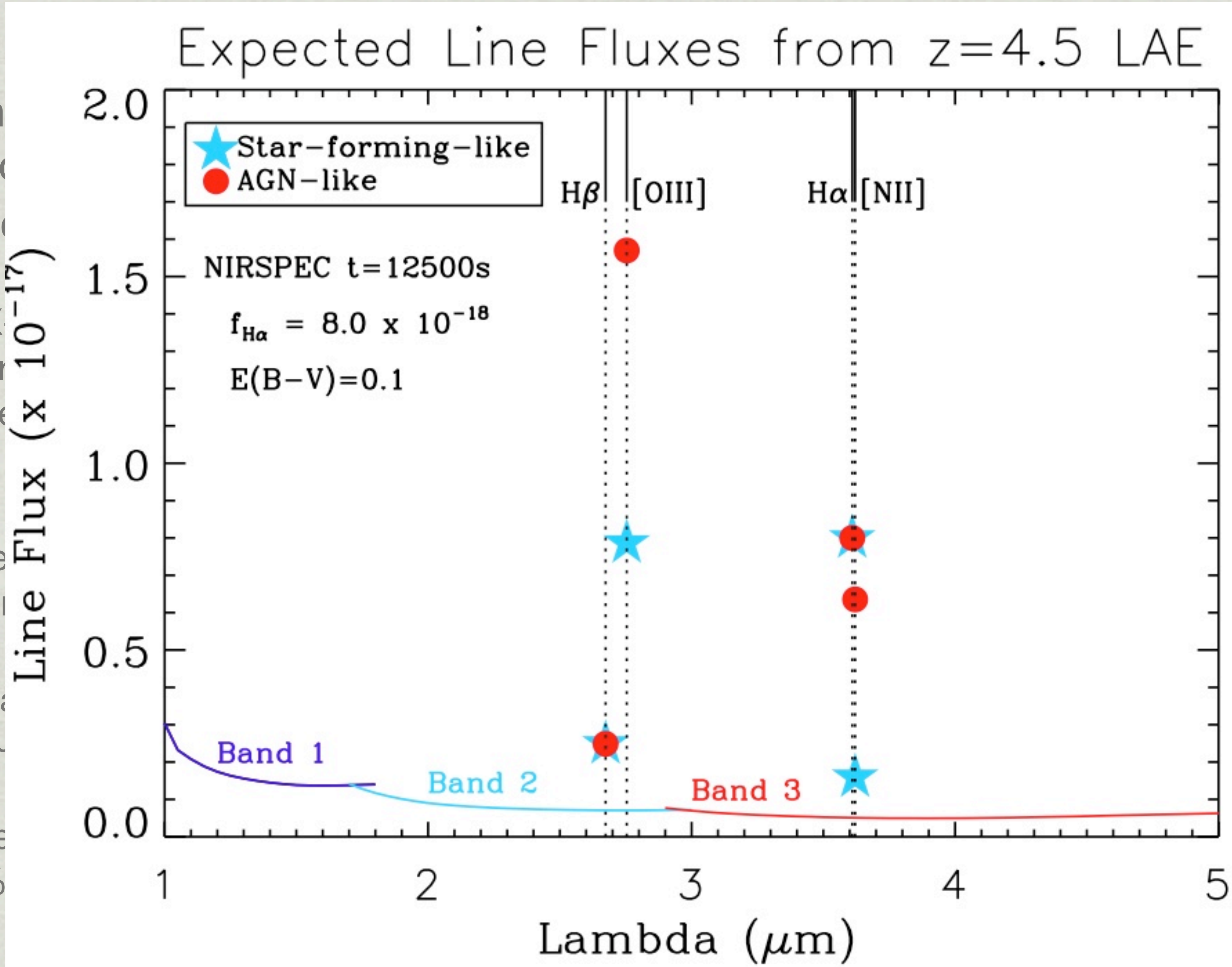


formation at these redshifts could result in similar emission.

Evolution in LAE AGN Fraction?

- Assigned a confidence level to the identification of AGN, based on number of methods and confidence in the method, and found a AGN fraction in LAEs of **43^{+18}_{-26} %**.
- Using X-ray data at high-z, AGN fractions have been found to range from 1-5% among LAEs (Malhotra et al. 2003; Wang et al. 2004; Gawiser et al. 2006; Ouchi et al. 2008; Nilsson et al. 2009; Lehmer et al. 2009), with upper limits as high as 17% using optical spectra (Wang et al. 2009).
- However, at most three of our methods (line widths, high ionization emission and X-ray emission) have been applied in LAEs at $z > 3$.
    - Reclassifying with only these methods, we find an AGN fraction of 26%, which still implies evolution from high-z.
- When restricted to measurements available at high-z, we would misclassify anywhere from 15-40% of our sample.
- This leads us to conclude that high-z LAE AGN fraction measurements may be at best lower limits. High-resolution IR imaging and MIR spectroscopy from JWST will help resolve this.

Evolution in LAE AGN Fraction?



- Assign ... mber of metho ... AEs of $43^{+18}_{-2\ldots}$
- Using X- ... nong LAEs (Malhotr ... son et al. 2009; Le ... Wang et al. 2009).
- Howeve ... -ray emissio ...
  - Recl ... lies evolu ...
- When re ... ere from 15-40% ...
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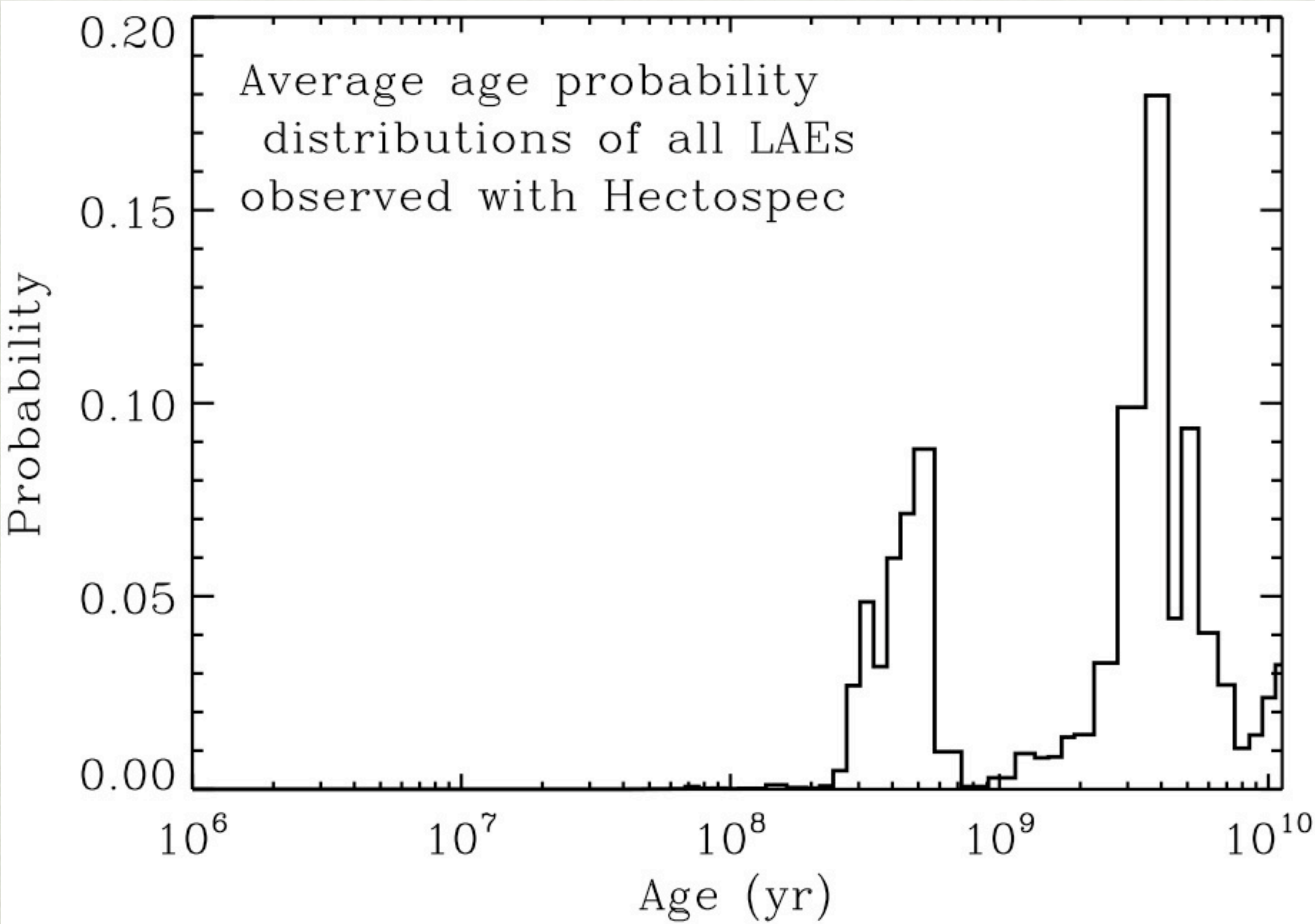
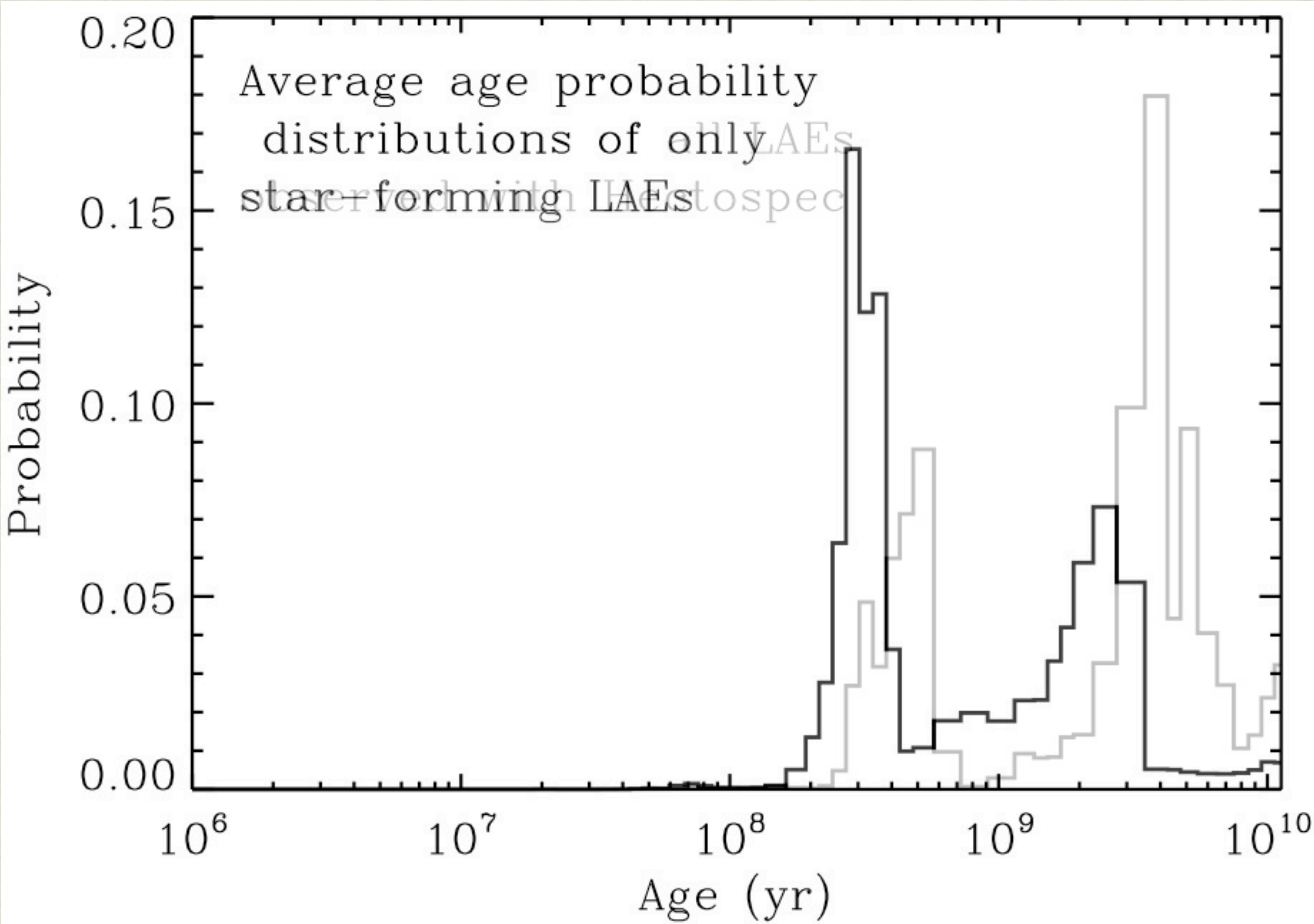
Back to Stellar Populations

- Discarding the probable AGNs, we now find that z ~ 0.3 LAEs have:
    - Age: 0.2 - 2.5 Gyr (mean ~ 0.8 Gyr)
    - Mass: 1 - 15 x 10^9 $M_\odot$ (mean ~ 5 x 10^9 $M_\odot$)


Average age probability
distributions of all LAEs
observed with Hectospec
Probability
0.20
0.15
0.10
0.05
0.00
10^6
10^7
10^8
10^9
10^{10}
Age (yr)


Average age probability
distributions of only
star-forming LAEs
Probability
Age (yr)
0.20
0.15
0.10
0.05
0.00
10^6
10^7
10^8
10^9
10^{10}

Summary

- At first glance, low-z LAEs appear to be much more evolved in age and mass than at their high-z analogs.
- Nearly half of them harbor AGN, which implies that the fraction of LAEs harboring AGN has increased dramatically.
  - Although, we note that using only the methods available at high-z, we would misclassify a good number of objects as star-forming.
- Discarding the AGNs, we still find a typical age and mass greater than that at high-z, although similar to the "massive" high-z LAEs.
- This supports a picture where the majority of LAEs at 3 < z < 6 are all galactic building blocks in the same phase of formation, whereas these low-z analogs represent very different objects, although possibly analogous to the massive LAEs at high-z.

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  - Lifan Wang